Nucleotomy Increases Disc Bending Stiffness under Complex Loading Modalities

Bo Yang, M.S., Yintong Lu,
Colin Um, and Grace D. O'Connell, PhD.

Introduction: Approximately 200,000 patients are diagnosed with a herniated disc each year [1], and the most painful cases undergo nucleotomy to remove herniated material and reduce pain. Previous studies showed that removal of the nucleus pulposus (NP) decreases joint stiffness in rotation and bending, increasing disc joint range of motion [2,3]. However, these studies only applied a single loading modality, which does not mimic the complex loading conditions experienced during physiological activities. We posit a compressive preload will greatly alter the mechanical behavior under bending and torsion following nucleotomy. Therefore, we evaluated disc joint mechanics under dual loading modalities after nucleotomy.

Method: We developed a structurally motivated finite element model of the human lumbar disc. The model was validated for compression, rotation, and bending using data in the literature (**Control**; Fig.1A) [4,5]. The NP was described as an isotropic hyperelastic material, while the annulus fibrosus was described as having nonlinear fibers within the extrafibrillar matrix (isotropic hyperelastic material). NP material was removed to simulate a nucleotomy (**Nucleotomy**, Fig.1B). A 936 N (0.48 MPa) compressive load was applied before torsion or bending moments were applied. Four angular displacements were evaluated: 6.5° flexion, 4° extension, 5° lateral bending, and 4° axial rotation (based on [6, 7]). Torques required to create these movements were recorded to create load-displacement curves and calculate joint stiffness as the change in torque divided by angular displacement.

Results: Control: The torque-rotation response was largely linear for both Control and Nucleotomy models (Fig. 1B), and the response of the Control model was within the range of experimental and computational results [8-12]. Torsional stiffness of the Nucleotomy model was 27% lower than the Control, but stiffness under extension, flexion, and lateral bending was ~50% higher than the Control (Fig.1B).

Discussion: Simulations of dual loading modalities showed that bending stiffness increases after nucleotomy, which disagrees with experimental studies that evaluated the disc mechanics under simple loading modalities (i.e., bending only) [2]. This discrepancy is likely due to fiber stiffening caused by larger deformations in the Nucleotomy disc under axial compression. Thus, the Nucleotomy disc experiences larger compressive strains in bending. An increase in bending stiffness with nucleotomy suggests more resistance to bending and a decrease in range of motion, which agrees with *in vivo* observations of severely degenerated discs [13]. In conclusion, simple loading modalities could not capture the effect of nucleotomy on *in situ* disc mechanics, and increases in disc stiffness following nucleotomy may lead to degenerative changes and remodeling.

[1] http://www.anationinmotion.org/value/disc/ [2] Cannella, 2009; [3] Putzier, 2005; [4] Peloquin, 2014; [5] Yang and O'Connell, 2017; [6] Yamamoto, 1989; [7] Pearcy, 1984; [8] Beckstein, 2008; [9] O'Connell, 2011; [10] Markolf, 1971; [11] Meijer, 2010; [12] Heuer, 2007; [13] Fujiwara, 2000.

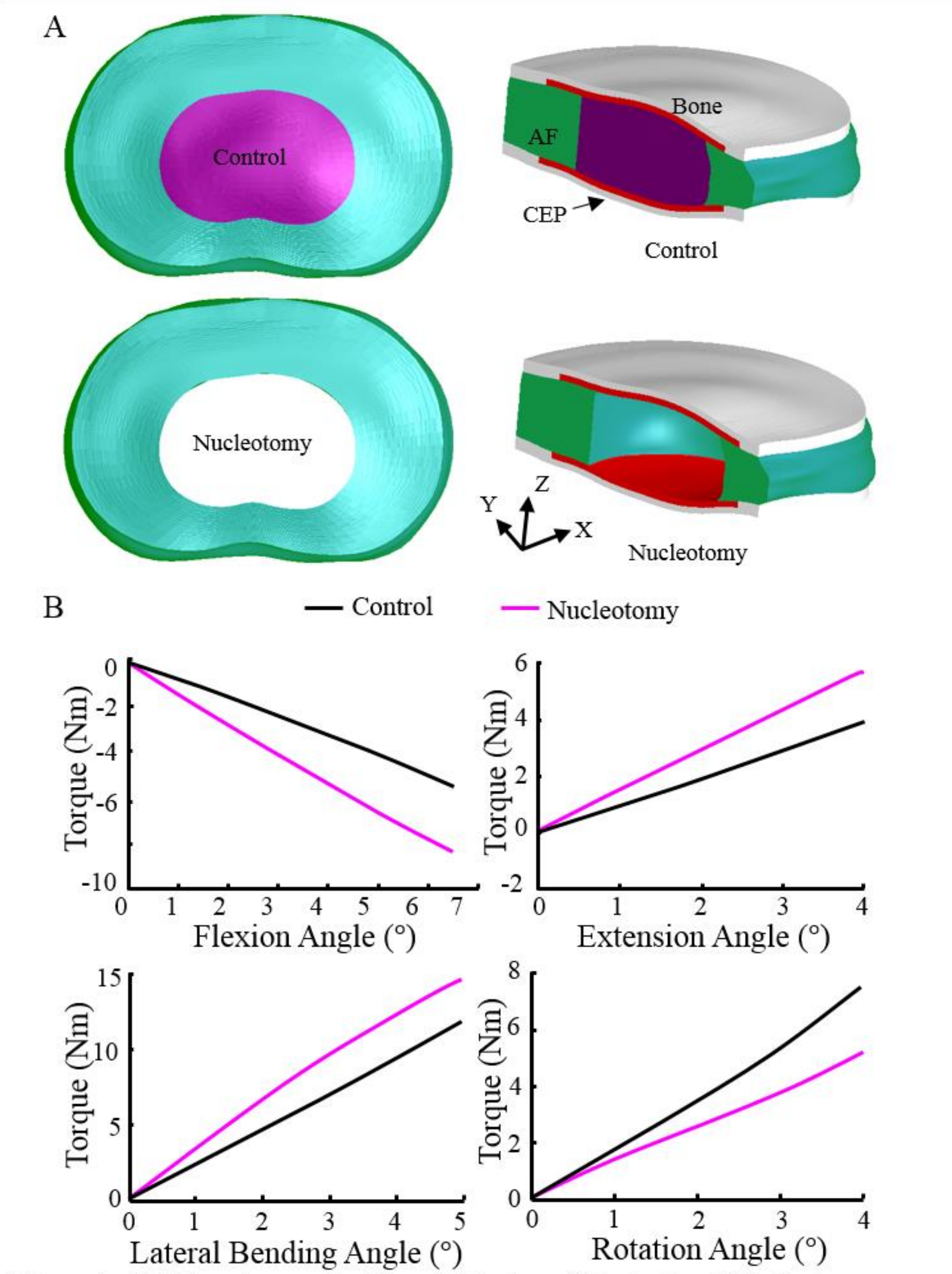

Figure 1. (A) Top view and mid-sagittal view of Control and Nucleotomy models. (B) Torque versus rotation angle for control (black) and nucleotomy (pink) models in flexion, extension, lateral bending, and axial rotation following a compressive preload. Stiffness was calculated as the slope of each line.