The Differential Decline in the Elastic and Viscoelastic Behavior within the Degenerating Intervertebral Disc

INTRODUCTION
Degeneration of the intervertebral disc (IVD) is a major cause of low back pain that often leads to reduced mobility. While the etiology of IVD degeneration is unclear, many studies have shown biochemical changes at the matrix level associated with age and degenerative disc disease (DDD). These biochemical changes may lead to altered mechanical properties of the IVD. Iatridis et al. [1] showed that age-related DDD exhibits an increased elastic modulus in compression but decreased tensile strength in the annulus fibrosus. The material properties of the disc have also been observed to be associated with the symptomatic or asymptomatic nature of the disease [2]. We aim to further delineate the relationship between the biomechanical properties of the IVD and the grade of degeneration.

METHODS
We analyzed 11 discs (T12 – S1 levels) from 2 human male cadaveric lumbar spines (60 and 80 years old). The intact lumbar spines were evaluated radiographically with MRI and fluoroscopy. Disc height, volume, and radiographic morphology were recorded. The discs were then harvested as a unit consisting of a disc, end plate, and bone segment. Transverse sections of the disc were obtained with a scalpel. The cross-sections of the disc were visually categorized into Thompson grades 1 to 5 [3]. This grading was corroborated with the fluoroscopic and MRI images.

The specimens were thawed to room temperature prior to MRI. Imaging was performed on a GE 3T EXCITE MRI scanner using a quadrature transmit/receive knee coil. (GE Medical Systems, Milwaukee, WI). A multi-slice multi-echo T2 sequence was used to acquire a field of view of 20 by 20, a 256 x 192 matrix, a slice thickness of 4mm, and NEX of 1. The repetition time (TR) was 2000 ms, and the individual echo times (TE) are as follows: 8.54, 17.07, 25.61, 34.14, 42.68, 51.216, 59.752, and 68.288 ms.

Dynamic microindentations were performed on transverse cross sections of IVD with the sample submerged in 0.15M PBS at 20°C using the BioDent1000 indentation system (Active Life Scientific, CA) [4]. The annulus fibrosus (AF) and nucleus pulposus (NP) were identified visually, with the AF tissue consisting of a lamellar structure that differed significantly from the gelatinous NP. Using a reference probe to determine surface contact, a 1.47mm diameter cylindrical probe cyclically indented the tissue to a depth of 300μm at 1Hz to generate a force-displacement curve. Three distinct sites per AF/NP were measured and averaged between the sites. The resulting force-deformation curves, accounting for the probe geometry, were used to compute elastic modulus and tan δ.

RESULTS
Both spines had discs that ranged from grades 1 – 5 on the Thompson scale (mean=3.0 ± 1.4). The AF indentation modulus increased proportionately with increasing severity of grade (GLM; p < 0.001) while NP modulus did not appear affected by grade (GLM; p = 0.86) (Figure 2). Tan δ correlated negatively with increasing Thompson grade in the NP (GLM; p < 0.001) but tan δ remained relatively unchanged in the AF with increasing grade (GLM; p = 0.95) (Figure 3).

DISCUSSION
Our results show that severity of degeneration differentially influences the elastic and viscoelastic behavior within the AF and NP. The indentation modulus of the AF increased with the degree of degeneration and is consistent with previous work [1]. The inverse relationship between tan δ and the Thompson grade in the NP shows that degeneration may be coupled with a loss of viscoelastic properties in the NP tissue of the IVD. This loss of viscoelastic behavior in the degenerating NP represents a reduced ability NP tissue to recover from cyclic deformations from physiological activities, and may contribute to symptomatic degeneration [2].

The changes in the material properties of the IVD may be due to changes in its matrix composition including loss of proteoglycans and increases in the accumulation of advanced glycation end-products (AGEs). The increased accumulation of AGEs has been observed in age-related DDD [5,6], adversely affects the strain energy of the AF [7], and may reduce the tissue’s hydration independently of proteoglycans [8]. Future work will involve determining the contributions of AGEs towards the biochemical, material, and permeability characteristics in the degenerating disc, and developing therapeutic strategies targeted towards the inhibition and reversal of AGEs formation to restore the functional properties of the IVD.

REFERENCES

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