INTRODUCTION:
Chronic low back pain affects an estimated 15-65% of the U.S. population\(^1\). Disc degeneration is often accredited with the cause of much of the low back pain experienced. With degeneration comes the breakdown of proteoglycans, loss of water content, and a decrease in the height of the intervertebral disc (IVD). These changes likely affect the disc’s viscoelastic response, making modeling and subsequent prediction of degeneration mechanics difficult. Unfortunately, much of the previous mechanical testing of intervertebral disc tissues has involved excision of the tissue and disruption of annular fibers. To gain insight into the in situ viscoelastic material properties, we have developed a new methodology of hybrid confined/in situ compression. Therefore, the purpose of this study was to define the viscoelastic properties of the intact intervertebral disc specific to degeneration grade and location.

METHODS:
Eight human cadaveric IVDs (L1-L2), acquired from the UM Bequest program, were subjected to stress-relaxation indentation tests performed with an Instron microtester (5548 Instron, Norwood, MA) equipped with a 3 mm cylindrical indenter tip. The loads were recorded using a 5 N uniaxial load cell. Prior to testing, an MRI (1.5T) was acquired for each spinal unit to determine the degree of degeneration (Thompson Grade). Specimens with grades 0-1 were categorized into the ‘Healthy’ group, grades 2-3 were labeled as ‘Moderate’, and grades 4-5 as ‘Severe’.

The adjacent vertebral bodies were left intact and attached to the IVD of interest. The inferior body (L2) was embedded in polymethylmethacrylate (PMMA), while the superior body (L1) was cut in half and the trabecular bone was removed, leaving the endplate visible and intact. A custom made jig was used in combination with a high speed rotary tool (diameter <1mm) to release a 3 mm diameter portion of the endplate which is contiguous with the IVD tissue inferior (Figure 1A). The rigid endplate, shown to have a modulus at least two orders of magnitude greater than annular tissue, provides a boundary connection to the indenter to facilitate hybrid confined indentation loading\(^2\). This technique was chosen to preserve the natural interaction of the IVD and the endplate whereby retaining annular fiber orientation which is disrupted in many of the previous investigations into disc properties.

Indentation tests were conducted at each of the following distinct locations: posterior-medial, anterior-medial, right-lateral, and left-lateral. Figure 1B depicts the four locations on the test specimen. Previous studies have reported right and left lateral symmetry, thus for this study they were grouped together. Local strains were computed using the measured disc height at each test location from MR images.

Following excision of the endplate, the released section increased in height, indicating the presence of an internal residual stress. The endplate was re-positioned back to its original height with the indenter tip and allowed to equilibrate for 1800 seconds. The residual stress was calculated. The tissue was then subjected to a 10% strain preload at a rate of 5% strain/second and allowed to relax for 1800 seconds. The preload was followed by an additional 5% strain applied at a rate of 5% strain/second relaxed for another 1800 seconds (Figure 2). The final stress-relaxation curve was fit to the following biphasic poroviscoelastic relaxation function, Eqn [1], described by Suh and DiSilvestro\(^3\):

\[
G(t) = 1 + g \sum_{i=1}^{3} e^{-t/\tau_i}
\]

Where \(G(t)\) is the stress relaxation function, \(g\) is the spectrum magnitude, and the \(\tau\) terms are the time constants of the function \((\tau_s=\text{short time constant, } \tau_L=\text{long time constant, and the final } \tau\text{ is the logarithmic average of } \tau_s\text{ and } \tau_L)\). Residual stress and equilibrium stress were defined as the asymptotic stress approached at 0% strain and 15% strain, respectively. Elastic modulus was measured on the loading ramp for the final 5% strain. The equilibrium modulus was found from Eqn [2]. Each of the outcome measures was compared with respect to degeneration grade and location using ANOVA techniques and an alpha acceptance of 0.05.

DISCUSSION:
The viscoelastic properties of the intervertebral disc were measured for various grades of disc degeneration in a location specific fashion. The residual stress and equilibrium modulus and stress were found to significantly correlate with grade of degeneration. These patterns were also specific to the location evaluated. The biphasic poroviscoelastic constitutive properties were identified for these discs to facilitate computational modeling of the intervertebral disc with sensitivity to both the location and health of the tissues to be modeled.

REFERENCES: