INTRODUCTION
The causes of low back pain are poorly defined and indistinct; most often implicated as the origin of pain is the intervertebral disc (IVD). Traditionally, a clinical exam assessing functional range-of-motion coupled with T2-weighted MRI (Fig 1B) revealing disc morphology are used to evaluate spinal health, but they fail to correlate well with pain or provide useful patient stratification [1,2].

Improved imaging techniques, such as quantitative T2* MRI, probe the biochemical properties of tissues, specifically interrogating the water mobility in the macro-molecular network (Fig 1A&C) [3,4]. This is particularly beneficial in detecting the early stages of IVD degeneration, where a decrease in proteoglycans in the nucleus pulposus leads to dehydration and diminished pressurization. Ultimately, these changes to the IVD alter kinematics and stability of the spinal segment.

This study aimed to define the relationship between disc degeneration, quantitatively assessed using magnetic resonance imaging and i. local disc biochemistry, ii. local compressive mechanics, and iii. global functional lumbar spine mechanics.

METHODS
Eighteen cadaveric lumbar spines (L3-S1), acquired from the UofM Bequest Program (53.2±15.5 yrs; range: 21-71 yrs), were imaged using a Siemens 3T MRI scanner (Magnetom Trio; Siemens Healthcare, Erlangen, Germany). Quantitative T2* relaxation maps (MapIt, Siemens Healthcare, Erlangen, Germany) were obtained using the following imaging parameters [TR(ms): 500; TE(ms): 4.18, 11.32, 18.46, 25.60, 32.74, 39.88; Voxel Size(mm): 0.5x0.5x3.0, Slices: 33]. Utilizing MATLAB (Mathworks Inc. Natick, MA), the central ROI mean relaxation value was evaluated in the coronal plane as the intensity changed from lateral to medial to lateral (Fig 2). Based upon Pfirrmann grading criteria, this method quantified the transition zone by computing the slope and intensity by integrating under the curve, altogether defining IVD health.

In a six-axis Spine Kinetic Simulator (8821 Biopuls, Instron, Norwood, MA), specimens underwent flexion-extension and lateral bending in a pure moment fashion up to 7Nm. Range of motion (ROM), neutral zone ratio (NZR), and bending stiffness were measured. Helical axes (HA) of the L4-L5 spinal segment were computed every 0.05° and averaged over a 1Nm window from -6.5Nm to 6.5Nm [5]. The orientation and location of the HA vector were used for comparison with disc health.

Subsequent experiments probing the local biochemistry and compressive mechanics of the L4-L5 discs were performed at five ROIs (Fig 3). Stress relaxation tests were performed using the hybrid confined/in situ indentation test, which utilizes the cartilaginous endplate as the porous indenter. The residual stress and strain were recorded [6].
Each test site was then excised and sulfated-glycosaminoglycan (s-GAG) was measured using a 1,9-dimethylmethylene blue assay. Pearson’s correlation tests were performed between each measurement and disc health (T2* values).

RESULTS AND DISCUSSION
T2* relaxation time was significantly correlated with the s-GAG content (p<0.047) in a site-specific fashion. T2* relaxation times of the NP, iAF, and oAF were significantly correlated with both excised strain and residual stress. The pAF T2* time was also correlated with residual stress. These relationships were particularly strong in the NP and iAF (Fig 5).

There was also a measured change in global spine kinematics as a result of disc degeneration. The T2* Intensity Area and the Transition Zone Slope were both significantly correlated with flexion and lateral bending ROM, NZR, and bending stiffness (p<0.044), but not extension.

The lateral bending HA patterns of the L4-L5 functional spinal unit were also affected by the quality of the IVD (Fig 4). There was a significant correlation between the orientation and location of the HA vector and T2* parameters of disc health, particularly at the end ranges of motion. The HA patterns indicate the more degenerative IVDs have more out-of-plane rotation.

REFERENCES

ACKNOWLEDGEMENTS
Funding from NIH/NIAMS T32 AR050938 ‘Musculoskeletal Training Grant’