Feasibility of Detecting Spinal Instability in a Goat Spine Segment Using MR Elastography

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Introduction: It has been reported that up to 85% of people will experience low-back pain (LBP) in their lives.[1] Degenerative disc disease (DDD) and spinal instability are two of the most common causes of LBP. There are many imaging techniques that have been developed to characterize the disc and grade the level of degeneration, but there is no way to directly assess the material properties of the IVD *in vivo*. The nucleus pulposus has been shown to undergo substantial changes in shear stiffness with degeneration.[2] Magnetic resonance elastography (MRE) is a sensitive, phase contrast-based imaging technique for non-invasively mapping the mechanical properties of tissues.[3] Cortes et al demonstrated the feasibility of using MRE at very high frequencies in the IVD *in vitro* to estimate the nucleus pulposus stiffness.[4] However, there has been no attempt at using MRE to measure the shear vibration response in a spine segment. The *purpose* of this study is to determine if MRE is capable of detecting spinal instability in an *in vitro* goat spine segment with induced disc degeneration and mechanical destabilization. The target audience of this research is MRI scientists involved in developing spinal imaging methods, radiologists involved in spinal imaging, clinicians involved in managing patients with low-back pain and disc-related spinal disorders, and basic scientists investigating DDD. Also, scientists working in MRE technique development may have interest in this research.

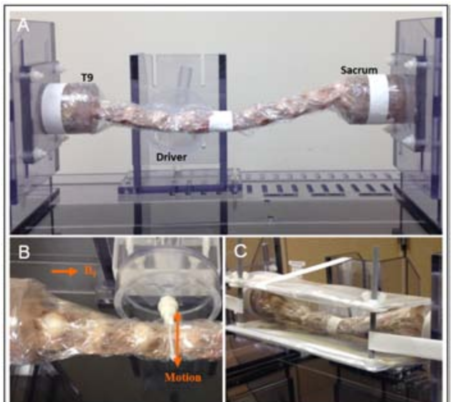

Figure 1: Experimental setup for performing MRE on the spine segments. Top (A): Custom experimental setup for testing spine segments with both ends fixed and applying shear vibration to the spine segment. The ends of the spine are labeled accordingly, and the driver is attached to the T12 vertebral body in all cases. Bottom left (B): A passive, pneumatic driver is rigidly attached to the spine and shear motion is applied perpendicular to B_0 and the length of the spine column. Bottom right (C): A two-channel, rectangular receiver coil was placed around the spine segment for each condition tested.

Methods and Materials: (1) Intervertebral Disc Specimens. An entire goat thoraco-lumbar spine (T8-S1) was removed with musculature and ligamentous structures intact. All posterior elements of the spine segment were removed to increase flexibility of the specimen, such that the entire spine segment consists of only vertebral bodies and discs. (2) Test Conditions. First, the control was taken as the spine segment before any alterations. Then, a series of four changes were made to the spine sequentially to cause varying amounts of mechanical instability: 1 – Trypsin solution was injected into the L2/L3 IVD to induce disc degeneration, as demonstrated in an *in vitro* animal model for disc degeneration.[5] 2 – Partial cut through the posterior annulus of L1/L2 IVD (cut 1). 3 – Partial cut through the anterior annulus of T11/T12 IVD (cut 2). 4 – Completely cut through T11/T12 disc (cut 3). There was also a no motion case collected for comparison. (3) Mechanical vibration. A passive, pneumatic driver was used to apply mechanical vibrations at 120 Hz to the spine segment. Using a custom spine testing fixture, the spine segment was fixed on both ends and then the driver was positioned such that shear vibration was applied to the T12 vertebral body (fig. 1A). The spine was rigidly fixed to the surface of the driver (fig. 1B). A two-channel, rectangular receive coil was placed around the spine with the length of the spine parallel to the B_0 direction (fig. 1C). The vibration direction was perpendicular to the B_0 direction and the spinal column. (4) Wave imaging sequence. The disc specimens were imaged using a spin echo-based MRE sequence with the following parameters: 2 total cycles of 120 Hz motion-encoding gradients (2.4 Gauss/cm), motion sensitivity = $13.9 \mu m/\pi$, offsets = 4, 166.7/41-ms TR/TE, 30-cm FOV, one 10-mm slice, 256x128 matrix, 2 NEX. A standard 1.5T full-body MRI scanner (Signa 16X Software, GE Healthcare, Waukesha, WI) was used in the experiment. For all experiments, a sagittal slice was taken through the center of the spine segment. Motion encoding was done in the R/L (through-plane) direction (5) Data analysis. The resulting phase images were then masked and phase unwrapped. The unwrapped phase images were then bandpass filtered (0.1-20 waves per FOV) and interpolated to 8 offsets, which gives the interpolated wave images (fig. 2C). The unwrapped phase images were also Fourier transformed over time. The magnitude of the 1st harmonic (120 Hz) of this FFT is shown in Figure 2C. Line profiles were drawn from T10 to L3 on these FFT magnitude images for each testing condition to see the effect of each on the 120 Hz shear vibration.

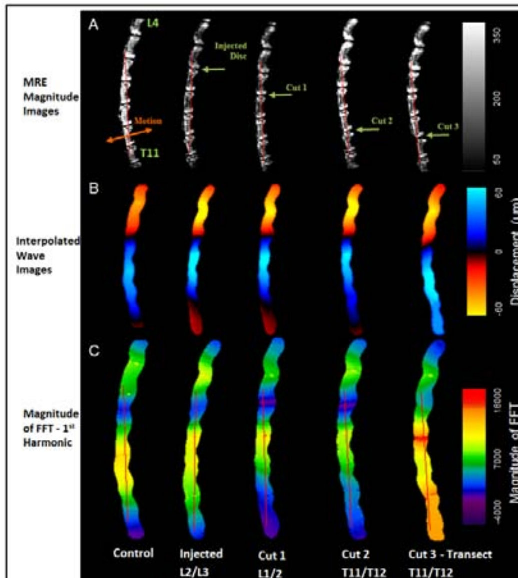

Figure 2: Top row (A): MRE magnitude images of goat spine segment. Middle row (B): representative interpolated wave images after filtering with a Gaussian bandpass filter with cut-offs of 0.1 and 20 waves/FOV. Color bar indicates the motion amplitude measured with MRE. Bottom row (C): the magnitude of the 1st harmonic (120 Hz) from the FFT, taken over time, of the unwrapped phase images. Color bar indicates the relative magnitude of the FFT 1st harmonic. Red lines indicate the line profiles used to generate the plot in Figure 3.

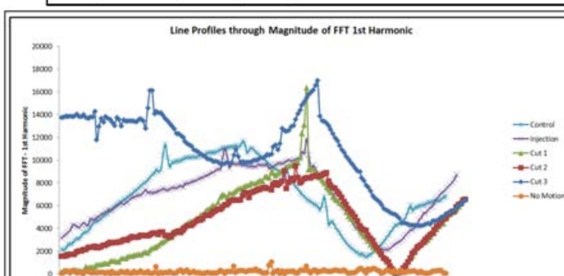

Figure 3: Plot of line profiles shown in Figure 2 from T10 – L3 of the magnitude of the FFT at the 1st harmonic for each of the spine conditions. NOTE: The lines are not perfectly matched for their position along the spine due to slight differences in the prescribed slices between conditions.

Results and Discussion: As shown in Figure 2, shear waves were seen in the entire spine segment for all conditions tested. The line profiles of the magnitude of the FFT 1st harmonic for all spine conditions are plotted in Figure 3. The induced disc degeneration and first 2 disc cuts changed the shear wave propagation and caused minor blips and jumps in the line profiles. But, the transected disc (cut 3) showed a very clear boundary in the magnitude of the FFT, as well as the wave images.

Conclusions: These initial results suggest MRE may be capable of detecting spinal instability. Additionally, the data shows that low frequency MRE (~120 Hz) can be used to vibrate the entire spine from a single vibration source. Further work is needed to determine and improve the detectability of small changes in local spine mechanical properties.

References: **1.** Andersson, G., B., J., Lancet, 1999. 354(581-5). **2.** Iatridis J, et al., J Orthop Res 1997, 15(2). **3.** Muthupillai R, et al. Science 1995. 269(1854-7). **4.** Cortes D, et al., MRM 2013. **5.** Roberts S, et al. BMC Musculoskelet Disord 2008. 9(24).