Frequency dependant shear properties of bovine ex vivo intervertebral disc.

Delphine Perie[1], Pierre-Francois Beauchemin[1], Phil Bayly[2], Joel R Garbow[2], John Schmidt[2], Ruth Okamoto[2], and Farida Cheriet[1]
[1]*Mechanical Engineering, Polytechnique Montreal, Montreal, Quebec, Canada,* [2]*Mechanical Engineering and Materials Science, Washington University in St. Louis, Saint Louis, Missouri, United States*

TARGET AUDIENCE: Physicist, biomedical engineers and orthopaedists investigating intervertebral disc material properties.

PURPOSE: Aging and degeneration have been shown to be associated with changes in mechanical properties in the intervertebral disc [3, 4], generating interest in the use of mechanical properties to establish early biomarkers for the degenerative cascade. Magnetic resonance elastography (MRE) is a powerful tool allowing acquisition of complete displacement fields. MRE experiments of the intervertebral disc are usually limited to the nucleus pulposus, as the annulus fibrosus is stiffer and less hydrated, making acquisition of displacement fields more difficult. The objective was to adapt high frequency needle MRE to the characterization of the shear modulus of both nucleus pulposus and annulus fibrosus.

METHODS: Intervertebral discs (n=3) were removed from fresh oxtails and characterized by needle MRE (Figure 1). The needle was inserted in the center of the disc and vibrations were generated by an amplified piezoelectric actuator in constant motion throughout the experiments to obtain steady-state motion. MRE acquisitions were performed on a 4.7T Agilent/Varian DirectDrive™ small-animal MR scanner using a spin echo sequence with sinusoidal motion encoding gradients (gradients amplitude of 15 G/cm, TE of 23-26 ms). Acquisitions were repeated over the frequency range: 1000 Hz, 1200 Hz, 1400 Hz, 1600 Hz and 1800 Hz. A Gaussian filter was applied for noise reduction and a temporal fast Fourier transformation was performed to extract the motion components at the excitation frequency. The local frequency estimation (LFE) inversion algorithm [1], the simple algebraic inversion of the differential equation (AIDE) algorithm [2], the virtual field method (VFM) [3] and the weak formulation (FF) method [4] were used to compute the shear modulus. In all cases, only one through-plane motion component was considered. Implemented algorithms used central finite difference for derivative calculations.

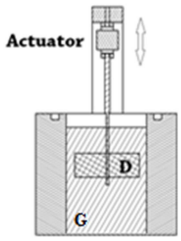

Figure 1: MRE set-up

RESULTS: Stiffness maps generated with LFE (Figure 2, left) allowed visualization of the soft nucleus pulposus surrounded by the stiffer annulus fibrosus surrounded by the homogenous gel. Stiffness maps generated by AIDE were less clear and application of a mask was necessary to eliminate negative or extremely high aberrant estimates. FF and VFM produced average values for the region of interest because of the integration terms. A significant difference in shear moduli was observed between the nucleus pulposus (Figure 2, middle) and annulus fibrosus (Figure 2, right) using the LFE algorithm only. For all algorithms, the shear modulus in the annulus fibrosus was higher than in the nucleus pulposus and high standard deviations were associated with data at 1000Hz.

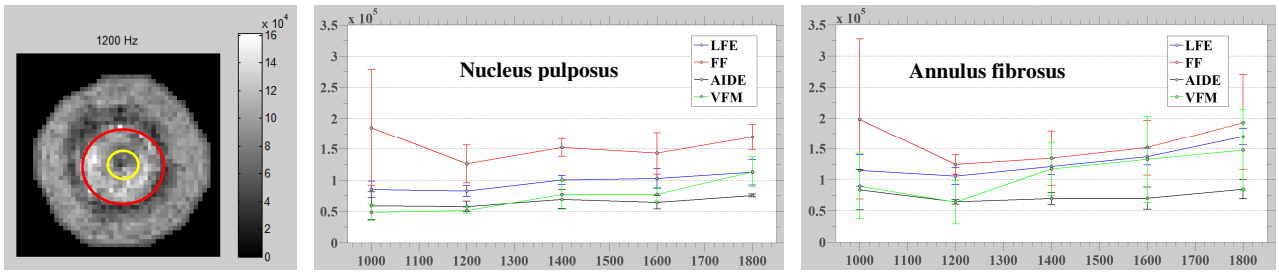

Figure 2: Shear moduli (Pa) from LFE at 1200Hz (left) within the annulus fibrosus (red circle, ~3 cm diameter) and nucleus pulposus (yellow circle, ~1 cm diameter), and from the 4 algorithms for all frequencies from 1000 to 1800 Hz.

DISCUSSION: Performing intervertebral disc MRE is a complex task because of tissue small size, high stiffness and low MRI signal. For small samples, the trade-off between having enough wavelengths in the tissue and enough voxels per shear wave is critical, as both can affect inversion algorithms performance. For all algorithms, high standard deviations were associated with data at 1000 Hz due to longer wavelengths responsible for uncertain estimations of the shear modulus. An increase of shear modulus with excitation frequency was observed both in the annulus fibrosus and nucleus pulposus, in agreement with the literature. Important variations were observed in the results of the different inversion algorithms, showing the importance of determining the best algorithm for a particular application.

CONCLUSION: This study demonstrated that global characterization of the intervertebral disc was possible with needle MRE using a preclinical MRI scanner. The advantages and limitations of different approaches to the inversion problem in the intervertebral disc were also determined. MRE can be a powerful method for mapping the complex properties of the intervertebral disc without requiring multiple tests and biopsies. The developed method could be adapted for *in situ* by preserving adjacent vertebras and puncturing the side of the intervertebral disc. This would allow the assessment of the contribution of osmotic pressure to the mechanical behavior of the intervertebral disc. Applications also exist for assessment of the effect of pathologies on the mechanical properties of the intervertebral disc.

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