High resolution $T1_\rho$ relaxation and dispersion imaging of intervertebral disc

R. R. Regatte[1], S. V. Akella[1], A. Borthakur[2], R. . Reddy[1]

[1]Radiology, University of Pennsylvania, Philadelphia, PA, United States, [2] Radiology, University of Pennsylvania, Philadelphia, PA, United States

Introduction:

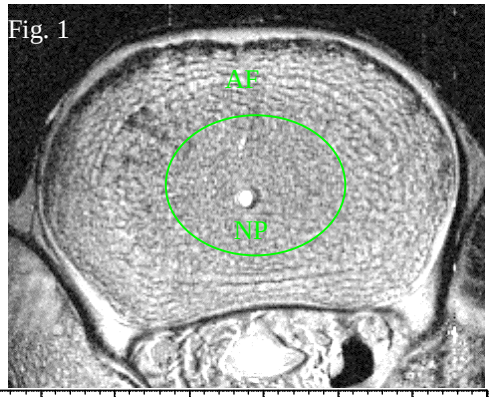
Intervertebral disc (IVD) degeneration has been implicated as a major etiological component of low back pain [1], a condition with tremendous disability, activity limitation, and economic loss. The disc consists of three anatomically distinct regions: nucleus pulposus (NP), annulus fibrosus (AF) and cartilaginous end plates (EP). The gelatinous NP located in the center of the disc, and the highly organized fibro cartilaginous AF in the periphery. The disc consists of almost 50% (dry weight) glycosaminoglycan (GAG) in the NP and only 15% (dry weight) GAG in the AF when compared to 20% (dry weight) in articular cartilage [2]. Such high concentration of GAG in NP produces an osmotic pressure in the range of 0.05-0.3MPa (0.5-3.0 atmospheres) [2]. Macromolecular composition, water content and structural changes in the disc are important determinants of the IVD disorders. The earliest biochemical changes in the disc are loss of GAG and decrease in water content in the NP with some structural changes (denaturation) of collagen [3]. The conventional MRI techniques such as T_1, T_2, and magnetization transfer (MT) are excellent for detecting the gross morphological changes (late stage) of the IVD disorders [3,4]. However, these techniques do not detect early degenerative changes, especially GAG changes in the disc, accurately. Although, sodium MRI is highly specific to GAG, but it has inherently low sensitivity, low resolution and requires high static fields for clinical applications. Due to limited diffusion of contrast agents into IVD, MR techniques based on exogenous agents are not useful for measuring GAG in IVD [5, 6]. The spin-lattice relaxation in the rotating frame ($T_{1\rho}$) is an alternative approach, which is sensitive to the slow macro-molecular interactions with the bulk water especially at low frequency range (0-100KHz). Previous studies from our group on cartilage (*in vitro* and *in vivo)* have demonstrated that the $T_{1\rho}$ is sensitive to changes in the GAG content of cartilage [7,8]. It has been shown that the $T_{1\rho}$ in the presence of residual dipolar couplings, is a bi-exponential decay [9]. However, in the current imaging experiments, we are probing only slow decaying components using the $T_{1\rho}$. The fast decaying components in IVD using spectroscopy are presented elsewhere. In the present work, we quantified spatial variation of the basal $T_{1\rho}$ relaxation times and dispersion in AF and NP of bovine IVD specimens.

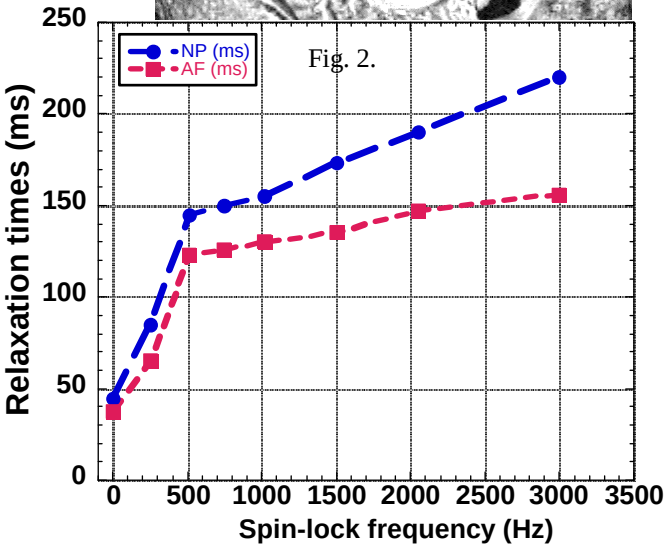
Materials and Methods:

Fresh IVD specimens (n=5) from young cows (~6-12 months of age) were obtained from a slaughter house (Bierig Bros., Vineland, NJ) within five hours of sacrifice. All the experiments were performed on an Oxford 4.7T horizontal bore magnet interfaced to a UNITY INOVA spectrometer (Varian, Palo Alto, CA) equipped with 12-cm gradients having a maximum strength of 25 gauss/cm. A 5.0 cm custom-built, linear birdcage radio-frequency (RF) coil tuned to 200.78 MHz was employed. Proton T_2 and $T_{1\rho}$-weighted images were acquired using multi-echo spin-echo and the $T_{1\rho}$ preparatory pulse cluster appended to a fast spin-echo (FSE) sequence [7], respectively. T_2 and $T_{1\rho}$ maps were computed by fitting the signal intensity to an appropriate signal expression using a linear least-squares method.

Results and Discussion:

Figure 1 shows the representative $T_{1\rho}$weighted image of a disc for B_1 = 500Hz (TE+TSL=45ms). In this image, the lamellar structure in AF (concentric layers of collagen fibers) can be clearly visualized. The imaging parameters were: TR/TE=4000ms/(TE+TSL)=45ms, in -plane resolution =137µm×137µm, slice thickness =1.0mm, acquisition time for each image=34 minutes, number of averages=2. $T_{1\rho}$ weighted image has higher signal to noise ratio (SNR) than the corresponding $T_{\square}$-weighted image (data not shown). **Figure 2** demonstrates the '$T_{1\rho}$-dispersion' in IVD. The data corresponding to a spin- lock frequency of 0 Hz are simply T_2- relaxation times. T_2 relaxation times range from 35-45ms whereas the $T_{1\rho}$-relaxation times range from 125-145ms, at a B_1 of 500Hz. The relaxation times are consistently higher in NP compared to AF over the range 0-3000Hz. The average $T_{1\rho}$-relaxation times are approximately 200% higher, at B_1=500Hz, when compared to T_2 relaxation times.





Conclusions:

The results show that $T_{1\rho}$ relaxation has higher dynamic range in IVD compared to T_2 relaxation. Higher dynamic range not only provides higher SNR and improved contrast between AF and NP but also improves the precision of relaxation measurement. Since NP has high PG content and low collagen content, dominant contribution to its $T_{1\rho}$ dispersion is exchange of protons on GAG with bulk water. These characteristics of $T_{1\rho}$ imaging may be exploited in quantifying GAG changes in the NP of IVD. Further studies in this direction are in progress.

References: 1) Herzog R et al, Am. Acad Ortho. Surg, (1996) 385, 2).Urban JP and McMullin JF, Spine 13 (1998) 385 3). Antoniou J et al, MRM 40 (1998) 900, 4) Chatani K et al, Spine 18 (1993) 2271, 5) Ross JS et al AJNR 152 (1989) 825, 6) Ibrahim MA et al AJNR 15 (1994) 1907, 7) Regatte RR et al JMRI 17(2003) 114. 8) Regatte RR et al Radiology 229 (2003) 269.9).Chaumette H et al, Mol. Phys 101 (2003) 1919