Self-Coregistered $T_{1ρ}$ and Sodium MRI of Intervertebral Discs

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Objective: ***To demonstrate correlation between Proton $T_{1\rho}$ and sodium MRI of the intervertebral disc***

Introduction:

Intervertebral disc (IVD) degeneration is a common and sometimes debilitating condition affecting a significant percentage of the population. The earliest stage of IVD degeneration involves the breakdown of proteoglycans (PG) in the nucleus pulposus (NP) region of the IVD[1]. The current diagnostic method for IVD degeneration relies on T_2 -weighted proton MRI, which is not sensitive to PG breakdown. $T_{1\rho}$ MRI has been shown to be sensitive to the interaction between large macromolecules like the PG and bulk water, thus it is potentially sensitive to the PG concentration in IVD. Sodium MRI has been shown to be an accurate measurement of PG content[2], since Na^+ cations are attracted by the fixed-charge density of the PG molecules. The purpose of this study is to demonstrate $T_{1\rho}$ as a measurement of IVD PG content, by correlating $T_{1\rho}$ relaxation time constants with $[Na^+]$ using self-coregistered proton $T_{1\rho}$ and sodium MR images of *ex vivo* IVD specimen.

Materials and Methods:

Four veal spine specimens were obtained from a local abattoir within a few hours of slaughter. The last three caudal discs on the posterior side of the specimen were surgically harvested. MRI was performed on a 3T Siemens Trio clinical MRI scanner. A custom-made platform was secured to the MRI scanner bed, and the specimen was secured to the platform as shown in Figure 1. The platform allowed proton and sodium RF coils to be switched without moving the IVD specimens. The sodium RF coil is a custom-made low-pass quadrature birdcage RF coil tuned to sodium resonance frequency at 3T. Five 10% agarose phantoms containing 100mM, 150mM, 200mM, 250mM, and 300mM Na^+ were imaged alongside each specimen for $[Na^+]$ calibration. The vendor's FLASH 3D MRI pulse sequence was used to acquire the sodium images. Sodium MRI parameters were as follows: TE/TR = 5.5/30 ms, flip angle = 90°, FOV = 15 x 15 cm, matrix size = 128 x 128, slices = 128, slice thickness = 1.2 mm, BW = 60 Hz/Pixel, signal average = 75. $T_{1\rho}$ MRI was done using the vendor's 8-channel birdcage RF coil, and a custom $T_{1\rho}$ prepared SPGR pulse sequence. The FOV and resolution parameters are identical to those of the sodium MRI. $T_{1\rho}$-weighted images at four spin-lock times (TSL = 10, 20, 30, 40 ms) were collected. The spin-lock amplitude was set at 500 Hz. Both sodium and $T_{1\rho}$ scans produced images with 1.2mm isotropic resolution, allowing us to reconstruct 2D images in any orientation. The sodium signals from IVDs and phantoms were corrected separately for T_1 and T_2^* decays. A calibration curve of phantom sodium MRI signal and their known Na^+ concentration was used to compute Na^+ concentration maps of the discs. $T_{1\rho}$ maps were computed on a pixel-by-pixel basis from the four $T_{1\rho}$-weighted images with different TSL, according to the following exponential equation: $S=S_0\exp(-TSL/T_{1\rho})$, where S_0 is the maximum signal intensity and S is the image signal intensity. A single user chose seven 3mm diameter ROIs along the anterior-to-posterior and the left-to-right axis, on the middle three axial slices of the IVD $T_{1\rho}$ map. Since the $[Na^+]$ maps and the $T_{1\rho}$ maps are self-coregistered, the ROIs were selected on the $T_{1\rho}$ maps and subsequently applied to the $[Na^+]$ maps. The average [Na+] and average $T_{1\rho}$ of all ROIs were used to construct a scatter plot with $[Na^+]$ measurement as the independent variable and $T_{1\rho}$ measurement as the dependent variable. Linear regression fit was applied to the data in the scatter plot to determine the extent of linear correlation between $[Na^+]$ measurements and $T_{1\rho}$ measurements in IVD.

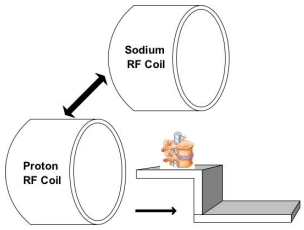

Fig 1. Experimental setup to acquire self-coregistered sodium and $T_{1\rho}$ MR images.

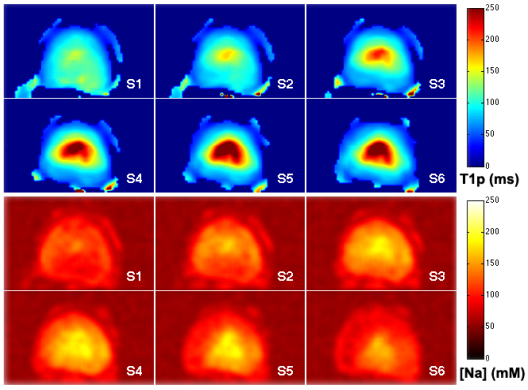

Fig 2. Six consecutive axial slices of self-coregistered $T_{1\rho}$ maps (top) and $[Na^+]$ maps (bottom). Corresponding colorbars were graphed on the right.

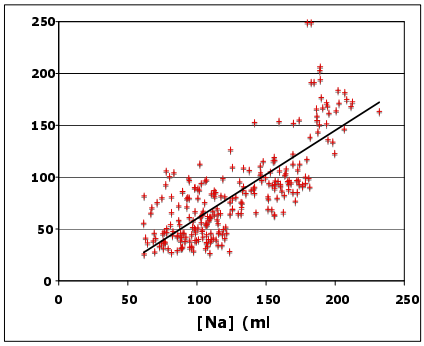

Fig 3. Scatter plot of ROI $T_{1\rho}$ vs. $[Na^+]$ measurements. The line represents the linear regression fit of the data, R=0.78.

Results:

Fig 2 showed six pairs of consecutive axial slices of the self-coregistered $T_{1\rho}$ and $[Na^+]$ maps. $T_{1\rho}$ maps and [Na+] maps followed similar trend, with the center of the NP having the highest $T_{1\rho}$ and $[Na^+]$ values. Both $T_{1\rho}$ and $[Na^+]$ decrease radially from the center of the NP to the outer annulus fibrosis (AF). In addition, the $T_{1\rho}$ maps demonstrated clearer boundary between NP and AF. Note the $[Na^+]$ maps appeared blurry when compared to the $T_{1\rho}$ maps. This is due to significant T_2 relaxation during signal acquisition, as a result of the short T_2 relaxation time constant of sodium nuclei. This T_2 decay during acquisition widens the voxel point spread function, resulting in blurring effect in the frequency encoding direction. Fig 3 shows the scatter plot of all ROIs' $T_{1\rho}$ measurements vs. $[Na^+]$ measurements. The linear regression fit revealed a positive linear trend between $[Na^+]$ measurements and $T_{1\rho}$ values, with a significant correlation coefficient of 0.78.

Conclusions:

In conclusion, our results demonstrated that disc $T_{1\rho}$ measurements correlated linearly with $[Na^+]$ obtained using sodium MRI. Although sodium MRI has been shown to be an accurate and non-invasive measurement of PG content in tissue, however its low SNR as well as hardware requirement limit its application in clinical settings. Instead, $T_{1\rho}$ is a magnetization preparation pulse that can be easily appended to most existing MR pulse sequence. It has higher SNR and does not impose any hardware requirements on clinical MR scanners. In the near future, we propose to conduct *in vivo* sodium and $T_{1\rho}$ MRI on subjects of a wide age range, to determine the *in vivo* correlation of $T_{1\rho}$ and $[Na^+]$ in IVDs at various stages of age-induced degeneration.

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2. Shapiro, E.M., et al., *23Na MRI accurately measures fixed charge density in articular cartilage.* Magn Reson Med, 2002. **47**(2): p. 284-91.