in vivo sodium MRI of Intervertebral Disc at 7 T

C. WANG[1,2], M. ELLIOTT[3], T. CONNICK[3], W. WITSHCEY[3], J. CALABRO[4], A. BORTHAKUR[3], and R. REDDY[3]

[1]SCHOOL OF MEDICINE, YALE UNIVERSITY, NEW HAVEN, CT, United States, [2]BIOENGINEERING, UNIVERSITY OF PENNSYLVANIA, PHILADELPHIA, PA, United States, [3]RADIOLOGY, UNIVERSITY OF PENNSYLVANIA, PHILADELPHIA, PA, United States, [4]SIEMENS MEDICAL SOLUTIONS, United States

Objective: ***To correlate intervertebral disc [Na^+] measured using sodium MRI in vivo at 7 T with degenerative grade***

Introduction:

Sodium MRI has previously been validated as a technique for non-invasive [Na^+], [PG] and FCD quantification[1], using *ex vivo* bovine intervertebral disc (IVD) samples. However, sodium MRI's role in the evaluation of IVD degeneration has yet to be quantitatively evaluated in an *in vivo* setting. In this study, we circumvented sodium MRI's low SNR by conducting the experiment at a 7 T MRI scanner, and correlated the IVD [Na^+] value with degenerative grades of the IVDs. In addition, magnetization transfer (MT) MRI has been shown to be correlated with IVD collagen density[2]. Therefore, the IVD NP [Na^+] values calculated using sodium MRI in this study were also compared to magnetization transfer ratio (MTR) and $T_{1\rho}$ values, which were acquired separately on a 1.5 T MRI scanner. MTR, $T_{1\rho}$ and [Na^+] together may reveal a more detailed picture of the not yet completely understood mechanism of IVD degeneration.

Materials and Methods:

Three human volunteers (mean age = 42) were recruited for this study. After consent was obtained, the subjects were instructed to lay supine on a Siemens 7 T clinical MRI scanner (Erlangen, Germany). A custom-engineered single-loop surface RF coil (diameter = 22 cm) tuned to 78.6 MHz was inserted underneath the subject's lumbar region. Sodium signal acquisition was carried out using a gradient echo (GRE) pulse sequence with the following sequence parameters: TR/TE = 320/8.77 ms, FOV = 400 x 400 mm, matrix = 128 x 64, slice thickness = 5 mm, number of slices = 32, NEX = 8, pulse duration = 2 ms, BW = 50 Hz/Pixel. The acquisition time was 24 minutes and 35 seconds. A single observer chose a 4 mm circular ROI in the center of each IVD NP. For each IVD, the NP [Na^+] value was computed by referencing it to the signal of the cerebro-spinal fluid of 150 mM [Na^+]. The subjects then underwent self-coregistered MT and $T_{1\rho}$ MRI on a Siemens 1.5 T MRI scanner. MT MRI was carried out using a custom MT-prepared turbo spin echo (TSE) pulse sequence with the following parameters: TE/TR = 7.5/2000 ms, FOV = 25 x 25 cm, matrix size = 256 x 256, slice thickness = 5 mm, BW = 296 Hz/Pixel, echo train length = 15, averaging = 3. The off-resonance saturation pulse was applied at 6.4 kHz down field of the free water proton resonance frequency, at a B_1 amplitude of 200 Hz. The off-resonance saturation pulse was applied in a pulsed fashion, with a duration of 300 ms for a TR of 2000 ms. A sagittal MTR map was acquired in 3 minutes and 44 seconds. $T_{1\rho}$ MRI was carried out using a custom spin-lock prepared TSE pulse sequence. The FOV and resolution parameters were identical to those of the MT TSE sequence. The imaging parameters were as follows: TE/TR = 13/3000 ms, slice thickness = 5 mm, turbo factor = 7, averaging = 2. $T_{1\rho}$-weighted MR images at five spin-locking times (TSL = 10, 20, 40, 60 ms) were collected, at a spin-lock amplitude of 400 Hz, for a total imaging time of 14 minutes and 56 seconds. A single observer then chose a 4mm ROI in the center of each IVD NP and obtained the MTR and $T_{1\rho}$ relaxation time constant value. At last, the Pfirrmann grade for each IVD was assessed using T_2-weighted MR images and the grading scheme described by Pfirrmann *et al*[3]. Two-tailed bivariate correlation analysis of the IVD NP MTR, [Na^+], $T_{1\rho}$ and Pfirrmann grade was performed using SPSS Statistics 18 software (SPSS, Chicago, USA). Pearson correlation coefficients were computed to elucidate linear relationships between Pfirrmann grade and IVD NP MTR, [Na^+] and $T_{1\rho}$ values.

Results:

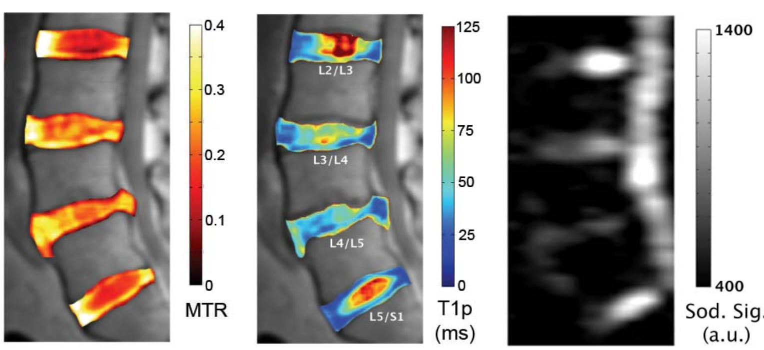

Fig 1. The self-coregistered sagittal lumbar MTR and $T_{1\rho}$ maps of a 54-year-old subject overlaid on top of the grayscale anatomical image. The sodium MR image of the same subject is shown on the right.

		[Na+]	T1p	MTR	Pfirrmann
[Na+]	Pearson Correlation	1	.672**	-.533*	-.678**
	Sig. (2-tailed)		.008	.049	.008
	N	14	14	14	14
T1p	Pearson Correlation	.672**	1	-.687**	-.666**
	Sig. (2-tailed)	.008		.007	.009
	N	14	14	14	14
MTR	Pearson Correlation	-.533*	-.687**	1	.774**
	Sig. (2-tailed)	.049	.007		.001
	N	14	14	14	14
Pfirrmann	Pearson Correlation	-.678**	-.666**	.774**	1
	Sig. (2-tailed)	.008	.009	.001	
	N	14	14	14	14

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 1. Table of Pearson correlation coefficients between all possible combination pairs of IVD NP MTR, $T_{1\rho}$, [Na^+] and Pfirrmann grades.

The lumbar IVDs shown in Fig 1 represent a wide range of degenerative grades. The L5/S1 IVD has a Pfirrmann grade of two; the L4/L5 IVD has a grade of four; the L3/L4 IVD has a grade of three; the L2/L3 IVD has a grade of two. The low Pfirrmann grade IVDs (L5/S1 and L2/L3) has low MTR in the NP, along with high $T_{1\rho}$ and high sodium signal. In contrast, the L4/L5 IVD with a high Pfirrmann grade, suggesting an advanced degree of degeneration, has high MTR in its NP with low $T_{1\rho}$ and weak sodium signal. In Table 1, the Pearson correlation coefficients indicate the existence of significant linear relationships between Pfirrmann grade and MTR, $T_{1\rho}$ and [Na^+]. MTR (indicative of collagen density) exhibits a positive linear correlation with Pfirrmann grade, while both $T_{1\rho}$ and [Na^+] (indicative of proteoglycan content) exhibit a negative linear relationship with Pfirrmann grade. MTR, $T_{1\rho}$ and [Na^+] are also linearly correlated to each other, with the correlation between $T_{1\rho}$ and MTR being the strongest. In each case, the linear correlation is significant with at least $p<0.05$.

Conclusions:

This study successfully quantified IVD NP [Na^+] *in vivo* on a 7 T MRI scanner, and demonstrated in an *in vivo* setting that the IVD NP [Na^+] decreases with degeneration. The preliminary *in vivo* data on the cross correlation of MTR, $T_{1\rho}$ relaxation time constant and [Na^+] proved the clinical viability of these MRI techniques, which makes it possible to quantify a set of IVD tissue biomolecular properties such as [Na^+] and collagen content non-invasively in a longitudinal study.

1. Wang, C., et al., *Validation of sodium magnetic resonance imaging of intervertebral disc.* Spine (Phila Pa 1976), 2010. **35**(5): p. 505-10.
2. Wang, C., et al., *Magnetization transfer ratio mapping of intervertebral disc degeneration.* Magn Reson Med. **64**(5): p. 1520-8.
3. Pfirrmann, C.W., et al., *Magnetic resonance classification of lumbar intervertebral disc degeneration.* Spine, 2001. **26**(17): p. 1873-8.