Mapping of Intervertebral Disc Long and Short T_2* Components at 7T

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Objective: Resolve intervertebral disc sodium long and short T_2* relaxation time constant and relative spin density at 7T

Introduction:

Sodium MRI of the intervertebral disc (IVD) is of particular interest to the study of IVD degeneration. IVD degeneration is initiated by the breakdown of proteoglycan in its nucleus pulposus (NP). Proteoglycan is a large and negatively charged macromolecule, which attracts positively charged Na+. Thus sodium MRI can be used to assess proteoglycan content within the IVD tissue. Despite its specificity for proteoglycans, sodium MRI has limited application in clinical settings due to its inherent low SNR. In this study, we presents the results from an exploratory investigation of 7T sodium MRI of *ex vivo* bovine IVDs. Utilizing the ultra high field strength and a radial acquisition UTE sequence, we measured the long and short T_2* component of sodium relaxation, as well as the corresponding long and short T_2 * sodium spin density values. The separation of the long and short T_2 * component is of special interest to studies that explore the intracelluar Na^+ vs. the extracellular Na^+ pools [1].

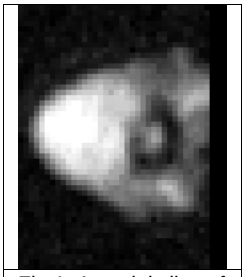

Fig 1. An axial slice of IVD with a TE of 220μs. The anterior side of the IVD points to the left.

Materials and Methods:

One veal spine specimen was 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 7T Siemens MRI scanner, using a custom made sodium birdcage RF coil. Siemens UTE sequence with radial k-space sampling was used to collect the sodium MR images. Sequence parameters were as follows: TR = 26 ms, flip angle = 40°, FOV = 25 x 25 cm, matrix size = 128 x 128, slices = 128, slice thickness = 1.95 mm, BW = 250 Hz/Pixel, radial spokes = 3000, TE = 220μs, 400 μs, 600 μs, 800 μs, 1ms, 3ms, 4ms, 5ms, 7ms, and 9ms. Signal averaging was increased three fold for the last five TEs in order to maintain adequate SNR for subsequent data analysis. Sodium nuclei's double exponential model of T_2* decay takes the following form: $S = N_s \cdot e^{-TE/T_{2s}} + N_l \cdot e^{-TE/T_{2l}}$, where N_s and N_l are the short and long T_2* components' spin densities. At long TEs (3ms~9ms), it was assumed that the short T_2* component had dephased completely, thus the previous equation can be simplified to: $S = N_l \cdot e^{-TE/T_{2l}}$. Exponential fit of the TE=3ms~9ms images would yield both T_{2l} and N_l values. For images with short TEs (220μs ~1ms), there are a combination of long and short T_2* relaxation. The previously solved values of T_{2l} and N_l were put back into the double exponential decay equation, allowing the computation of T_{2s} and N_s. The long and short T_2* component spin density fractions were calculated by dividing the corresponding spin density value by the total long and short spin density values. The above analysis was applied to four axial slices of the three discs. A single user selected a 3x3 pixel region-of-interest (ROI) from the NP center for each IVD. The ROI was subsequently applied to images of other TEs. The calculated T_{2l}, T_{2s}, long and short spin density values were reported in a table.

	T_{2l} (ms)	R_l	Long T2 Frac.	T_{2s} (ms)	R_s	Short T2 Frac.
Disc1	7.50	0.99	0.58	1.01	1.00	0.42
Disc2	10.88	0.98	0.52	1.11	0.98	0.48
Disc3	10.43	0.99	0.53	1.25	0.99	0.47

Table 1. Average center NP ROI relaxation parameter measurements.

Results:

Fig. 1 shows an axial slice of an IVD with a TE of 220μs. We achieved a SNR of 39 to 1 in the center of the NP with the previously described UTE sequence. ROI analysis of the center of the NP yielded the results illustrated in Table 1. The short and long T_2* maps of an IVD were overlaid on its grayscale image, shown in Fig. 2. Note Table 1. Showed that both the long and short T_2* components were calculated from excellent fit of the data points, demonstrated by the high correlation coefficients. The signal fraction of the long T_2* component is higher than the signal fraction of the short T_2 * component. The trend is further demonstrated in the signal fraction maps of a single IVD illustrated in Figure 3.

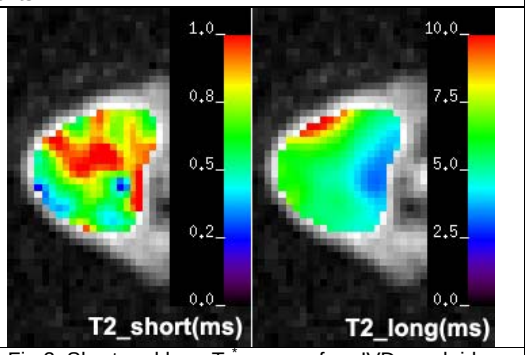

Fig 2. Short and long T_2^* maps of an IVD overlaid on top of the axial gray-scale sodium image.

Conclusions:

In conclusion, our results demonstrated that IVD sodium short and long T_2* components can be measured accurately using a UTE sequence at the 7T. The computed short and long T_2* signal fractions deviate slightly from the previous published ratio of 0.6 and 0.4 respectively. This is potentially due to the lack of cellular structure within the extracellular matrix of the NP, in comparison to the brain tissue. Furthermore, this technique would prove useful in applications when unknown tissue sodium concentration has to be calculated from calibration curve computed using sodium phantoms of known concentration. The sodium signals of the phantoms and tissues have to be compensated with respect to their corresponding short and long T_2* values, as well as the short and long T_2 * signal fraction.

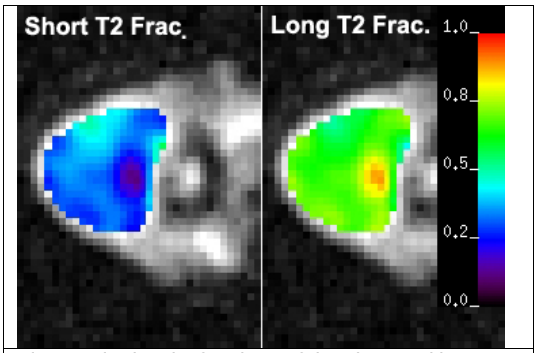

Fig 3. Spin density fractions of the short and long T_2 components overlaid on top of axial gray-scale sodium image.

1. Clayton, D.B. and R.E. Lenkinski, *MR imaging of sodium in the human brain with a fast three-dimensional gradient-recalled-echo sequence at 4 T.* Acad Radiol, 2003. **10**(4): p. 358-65.