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$. Thus sodium MRI can be used to assess proteoglycan content within the IVD tissue. Despite its specificity for proteoglycans, sodium MRI has limited application in clinical settings due to its inherent low SNR. In this study, we present the results from an exploratory investigation of 7T sodium MRI of ex vivo bovine IVDs. Utilizing the ultra high field strength and a radial acquisition UTE sequence, we measured the long and short T$_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 intracellular Na$^+$ vs. the extracellular Na$^+$ pools.

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, 400μs, 600μs, 800μs, 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$_2^*$ values, as well as the short and long T$_2^*$ signal fraction of the short T$_2^*$ component. The trend is further demonstrated in the signal overlay on top of axial gray-scale sodium image.

Results:
Fig. 1 shows an axial slice of an IVD with a TE of 220μs. The anterior side of the IVD points to the left.

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.