**Sodium MRI of Intervertebral Disc Degeneration**

**ABSTRACT INTRODUCTION:**
Degenerative disc disease (DDD) of the intervertebral disc is the most common cause of back-related disability among North American adults, affecting nearly 12 million people in the United States, and cost nearly 50 billion dollars in health-related expenditures. The initial phase of disc degeneration is marked by breakdown of proteoglycans (PG) in the extracellular matrix of the nucleus pulposus (NP). Previous studies had shown sodium MRI to be sensitive to PG content in articular cartilage tissue. In this study, we demonstrated the use of sodium MRI to quantify PG content in intervertebral discs, thus opening up the possibility for early diagnosis of DDD.

**METHODS:**
Two fresh whole veal lumbar spines were obtained from a local abattoir (Beirig’s Brothers, Vineland NJ), within a few hours of slaughter. MRI was performed on a 3T Siemens Trio clinical MRI scanner equipped with a broadband amplifier and receiver at the Hospital of the University of Pennsylvania. The sodium nuclei resonance frequency at 3T was 32.6 MHz. Tissue samples were placed inside a custom-made low-pass quadrature birdcage RF coil tuned to sodium frequency. Five 10% agarose gel phantoms containing 100mM, 150mM, 200mM, 250mM, and 300mM Na were attached to the specimen during scan, as shown in Figure 1. A 3D FLASH MRI pulse sequence was used to acquire all sodium images. The sodium imaging parameters were as follows: TE/TR = 6/30 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, for a total imaging time of 7 hours. The long scanning time was specific to the high spatial resolution needed for data analysis. In clinical applications, the spatial resolution would be reduced to scan time. The sodium signals of disc and phantoms were separately corrected with respect to their T_1 and T_2 relaxation. 3D [Na] maps of the discs were computed using the corrected phantom signals of known [Na]. After sodium MRI, the intervertebral discs were isolated via sharp dissection, leaving the annulus fibrosis (AF) and NP intact as shown in Figure 2. A series of ordered 4-mm diameter punches were harvested from the NP indicated in the overlay on Figure 2 for standard PG assay using 1,9-dimethylmethylene blue (DMMB). After punches were removed, the discs were photographed against a dark background using a digital camera. These photographs were used later to generate image masks for reporting [Na] values from the exact region where the hole punches were located. Photographs of each dissected disc were down-sampled to the same spatial resolution as the sodium MR images (1.2 mm²). A simple threshold followed by opening operation yielded binary image masks indicating the region of interest (ROI) where punches were removed. An automatic co-registration routine then applied step-wise in-plane rotation and translation of the mask over the [Na] map, while maximizing the linear fit between [Na] measurements of the ROIs and the PG assay results. The ROI standard deviation of [Na] was recorded as the error.

**RESULTS SECTION:**
![Figure 1](image1.png)

*Figure 1.* A representative axial slice of a colored disc MR image, surrounded by five agarose phantoms labeled with their sodium concentrations. The color scale on the right represents absolute signal intensity.

![Figure 2](image2.png)

*Figure 2.* Photo of a dissected disc, with boundary of AF and NP drawn on top. The numbered locations of the hole punches for the PG assay were labeled.

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**DISCUSSION:**
- A strong linear correlation exists between disc [Na] measured using sodium MRI and actual [PG]
- First known validation of sodium MRI as a non-invasive technique for the assessment of disc PG content
- Sodium MRI is potentially a promising clinical diagnostic tool for early stage DDD
- Sodium MRI could aid the development of new therapeutics aimed at mitigating disease progression