Registered $^{1}H/^{23}Na$ *In Vivo* Imaging of Human Articular Cartilage with 3D Cones Trajectory at 7T

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INTRODUCTION: Osteoarthritis is a highly debilitating disease afflicting tens of millions of people in the United States. Early signs of osteoarthritis involve changes in the matrix composition of articular cartilage including reduced proteoglycan concentration. Direct quantification of sodium in cartilage has been shown to correlate positively with proteoglycan content, making sodium MRI very attractive for tracking early degenerative changes [1-3]. However, sodium MRI is challenging for a number of reasons. Sodium exhibits a rapid bi-exponential signal decay, with a short T2* component of ~1-3 ms and long T2* component of ~10-30 ms. To capture most of the sodium signal, extremely short echo times and readout durations are required to avoid significant T2* blurring. Furthermore, sodium concentrations in the body are typically more than two orders of magnitude lower than ^{1}H, leading to very low signal. Lastly, the low gyromagetic ratio of ^{23}Na (nearly 4 times smaller than that of ^{1}H) reduces polarization sixteenfold, while increasing demands on gradient amplitudes to achieve adequate resolution. Therefore, successful imaging of sodium requires high SNR-efficiency and extremely short echo times. High field strength and custom sodium-tuned coils also greatly improve the sodium SNR for the anatomy being imaged.

We have developed a novel, relatively fast, high-resolution, high-SNR 3D sodium imaging sequence for rapid *in vivo* imaging of human articular cartilage in a 7T whole body scanner. We have also developed a protocol to register the sodium images with high-resolution anatomical proton images in order to correlate sodium content with the underlying cartilage morphology. Our technique achieves excellent sodium SNR in the patellar cartilage (Rayleigh-corrected SNR >= 13) at a resolution of 1.25x1.25x4mm^3 with minimal blurring in under 20 minutes of total scan time for both sodium and proton images.

METHODS: A fast gradient-spoiled sequence using a 3D cones k-space trajectory [4] and rapid RF excitation was used for sodium image acquisition. The centric 3D cones trajectory allows for extremely short echo times and very high SNR efficiency. The 3D cones trajectory shares some similarities with other radial spiral trajectories that are commonly used in sodium imaging (such as twisted projection imaging [5]), but allows more efficient use of the scanner gradient resources, enabling the high resolutions required for cartilage imaging.

The sodium sequence was implemented on a 7T GE Excite whole body scanner with HFD gradients (40 T/m max. gradient amplitude, 150 T/m/ms max. slew rate) using a $^{1}H/^{23}Na$ dual-tuned 5" surface coil (GE Healthcare, Waukesha, WI). The patellar cartilage of several normal volunteers was scanned to assess the performance of both the sodium imaging and image registration techniques.

Sodium acquisitions were obtained at voxel sizes of both 1.25x1.25x4mm and 1x1x2mm. Parameters for the larger voxel scan were: TR/TE = 50/0.6 ms, FOV = 16x16x12.8cm, matrix = 128x128x32, readout time = 8 ms, flip angle = 70º, and 16 averages for a total scan time of 17 min. We used similar parameters for the higher-resolution scan, except for readout time = 16 ms, matrix = 160x160x64, and a total scan time of 26 min.

The underlying ^{1}H images were acquired at a resolution of 0.4x0.6x2mm^3 using a 3D fast GRE sequence, FOV = 16x16x12.8cm, TE/TR = 2.8/8.5ms, a 2mm slice thickness, 25º flip angle, 384 points per readout and 256 phase encodes, leading to a total scan time of 2 min. 19 sec. The sodium image is then registered, color-mapped, and overlaid on the proton image, to show the sodium content of the features seen in the anatomical ^{1}H image.

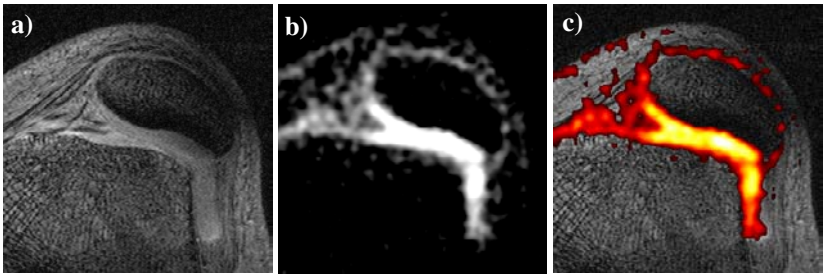

Figure 1: $^{1}H/^{23}Na$ registered images of the knee showing the patellar cartilage. **a)** ^{1}H image of the knee with a resolution of 0.4x0.6x2mm^3. **b)** ^{23}Na image of the same knee with a 128x128x32 matrix (1.25x1.25x4mm^3 resolution) over the same FOV. **c)** Sodium image (heat scale) overlaid on the proton image showing in color the sodium content of the voxel (red: low – orange – yellow – white: high)

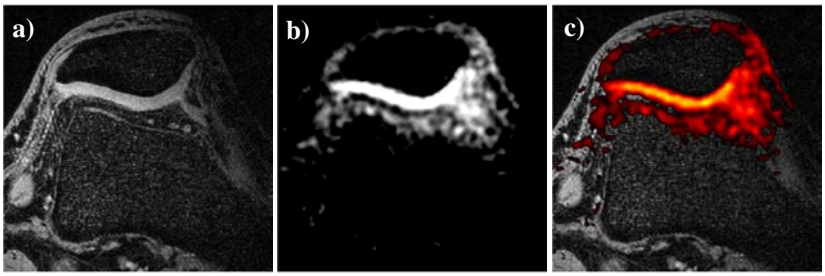

Figure 2: $^{1}H/^{23}Na$ registered images of the knee showing the patellar cartilage at a 1x1x2mm^3 sodium resolution. **a)** ^{1}H image of the knee with a resolution of 0.4x0.6x2mm^3. **b)** ^{23}Na image with a resolution of 1x1x2mm^3. **c)** Sodium image (heat scale) overlaid on the proton image with better delineated cartilage due to a thinner slice and reduced partial volume artifact.

RESULTS: We evaluated the patellar cartilage of the knee in axial sections of the 3D image. We were able to achieve ^{1}H images with a resolution of 0.4x0.6x2mm^3 and ^{23}Na images with a resolution of 1.25x1.25x4mm^3 (Figure 1). The Rayleigh-corrected SNR for the sodium image is 13. We were also able to register the anatomical ^{1}H image with the ^{23}Na image (Figure 1c). The sodium image was windowed and color mapped to show the sodium content information on the anatomical scan.

Using the same protocol as described above we were able to achieve a sodium image resolution of 1x1x2mm^3 and Rayleigh-corrected SNR of 9.5 (Figure 2). Images at this resolution show greater cartilage detail and less partial volume artifact from thick slices. With both resolutions we saw excellent delineation of the cartilage and a very good correlation of the morphology to the sodium concentration.

CONCLUSION: We have demonstrated the feasibility of using a fast 3D cones trajectory for the acquisition of high resolution sodium images registered with proton images achieving excellent SNR and resolution for sodium and protons *in vivo* in reasonable total scan times.

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