Anisotropic Twisted Projection Sodium MRI of Articular Cartilage in the Human Knee

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INTRODUCTION: As sodium levels in cartilage may reflect the pathology of osteoarthritis, several studies have examined sodium MRI as a potential diagnostic technique for cartilage health in vivo[1]-[3] . These studies used gradient echo (GRE) sequences with a large out-of-plane voxel dimension to maximize signal to noise ratio (SNR) and higher in-plane resolution to better visualize the structures. However, given the rapid biexponential T2 relaxation of sodium in knee cartilage, GRE techniques may be non-ideal as they necessitate longer echo times (TE 2-2.4 ms). Three dimensional projection imaging with hard nonselective radiofrequency excitation pulses has extremely short TE (<0.4 ms). 3D radial imaging has been used to image sodium in the knee[4], but the inherently spherical sampling of k-space leads to isotropic voxels, which may not be ideal given that knee cartilage is as thin as 1.7 mm[5] and has a wide surface area. The use of anisotropic k-space acquisition with 3D twisted projection imaging (TPI samples k-space more efficiently) could be beneficial as it minimizes voxel dimensions across the depth of the cartilage while maintaining voxel volume needed for SNR. The purpose of this study is to evaluate anisotropic 3D TPI for improved sodium MRI of human knee.

METHODS: Anisotropic 3D TPI voxels were attained by multiplying the out-of-plane gradient of each projection by a scaling factor, thus sampling k-space to an oblate spheroid (Figure 1). Two sampling density filtered[6] 3D TPI projection sets were designed, including one isotropic (nominal voxel size 1.37 x 1.37 x 1.37 mm^3) and one anisotropic (nominal voxel size 0.8 x 0.8 mm^2 in-plane, and 4.0 mm out of plane); both projection sets had the same sampled k-space volume and nominal voxel volume (defined by 1/(2*kmax)) of 2.56mm^3, as well as equivalent twist (p = 0.198) and readout length (17.6 ms). The isotropic set used 6750 projections (4 averages), while the anisotropic set used 9000 projections (3 averages), to yield the same number of total projection acquisitions. The sets produced the same SNR when images were acquired of a uniform spherical saline phantom. Sodium MR imaging (TE=0.21 ms, TR=25 ms, flip angle=74°, pulse width=0.3 ms, acquisition length 10 min) of a saline resolution phantom, as well as of the knees of three healthy volunteers was performed on a Varian Inova 4.7T whole body MRI scanner using a homemade single tuned 53 MHz knee RF coil.

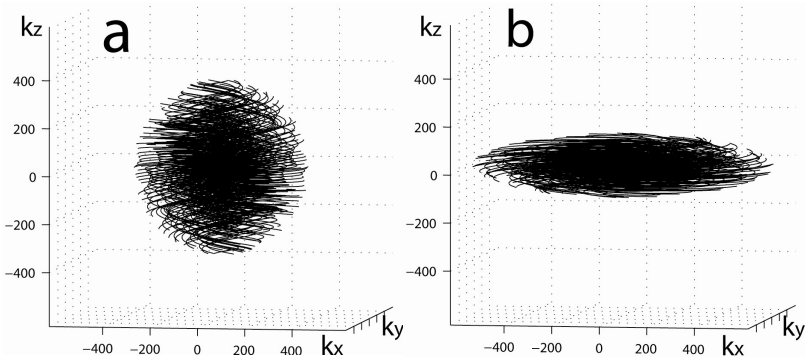

Figure 1: K-space projections for twisted projection imaging sodium MRI
(a) Isotropic set (sphere) (b) Anisotropic set (oblate spheroid)

RESULTS/DISCUSSION: The saline resolution phantom images (Figure 2) showed that the anisotropic acquisition achieved practical in-plane resolution of 1.4 mm, whereas it was poorer at 2.0 mm for the isotropic set. The higher in-plane resolution and sharper structural delineation is also evident in the human knee sodium images (Figure 3). Due to low signal intensity and/or extremely thin cartilage in the superior posterior femoral condoyle (indicated by red arrows), there is little to no signal in the isotropic images, while the anisotropic images clearly show tissue. In addition to the obvious visualization benefits, anisotropic voxels are more efficiently placed within the cartilage, leading to reduced partial volume effects (which should aid in sodium quantification). While the anisotropic voxels are larger out-of-plane than the isotropic ones, the anatomy of the knee permits this, as femoral cartilage here runs perpendicular to the sagittal plane. Due to the benefits of increased resolution and reduced partial volume effects, anisotropic 3D TPI should be considered as an effective acquisition method for sodium MRI of knee cartilage.

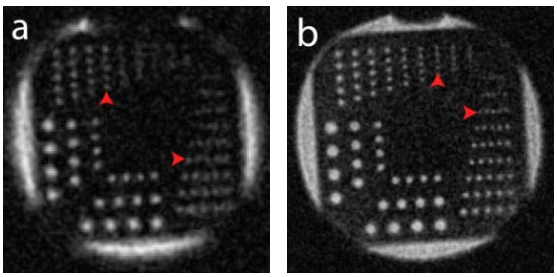

Figure 2: Representative resolution saline phantom images. Hole diameters are equivalent to their spacing for each set, ranging from d=5.0 mm to d=1.0 mm. Arrows indicate effective resolution.
(a) Isotropic set (b) Anisotropic set

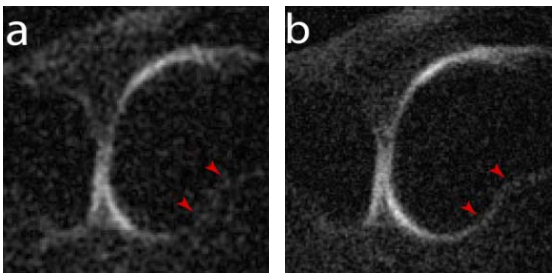

Figure 3: Sagittal sodium images of a human knee (right lateral condoyle) in vivo. Arrows indicate regions where signal loss occurs in isotropic images but not in anisotropic images.
(a) Isotropic set (b) Anisotropic set

References: [1] Wheaton, Radiology **231**(3): 900 (2004) [2] Reddy, MRM **39**(5): 697 (1998) [3] Shapiro, MRM **47**(2): 284 (2002) [4] Wang, J Magn Reson **30**(3): 606 (2009) [5] Shepherd, Ann Rheum Dis **58**(1): 27 (1999) [6] Stobbe, MRM **60**(4): 981 (2008)