Comparison of SPGR and Balanced SSFP for Sodium Knee Imaging

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INTRODUCTION: Early degenerative changes in articular cartilage leading to osteoarthritis are accompanied by proteoglycan depletion in the cartilage matrix. Sodium MRI has been shown to correlate with proteoglycan concentration [1-3], and may be useful in detecting and tracking early proteoglycan depletion. Sodium MRI is challenging due to relatively low ^{23}Na concentrations in biological tissues, a rapid signal decay, and a low gyromagnetic ratio. Despite these challenges, improved coils and gradient hardware coupled with higher field strengths enable diagnostic-quality sodium MRI *in vivo* in reasonable scan times [4].

In order to accurately track sodium signal in cartilage, the signal contribution from synovial fluid should be minimized. Here we studied the contrast between fluid and cartilage generated by sodium SPGR and balanced SSFP (bSSFP) sequences across a range of flip angles.

METHODS: All data was acquired on a 3T GE Signa Excite whole-body scanner (GE Healthcare, Waukesha, WI) using the 3D cones k-space trajectory [5]. The centric 3D cones trajectory permits short echo times and achieves very high signal-to-noise ratio (SNR) efficiency, while providing a relatively smooth k-space weighting and making efficient use of gradient resources.

A sodium-tuned birdcage knee coil was used for image acquisition. Both the SPGR and bSSFP sequences achieved a resolution of 1.3×1.3×4 mm^3 over a field of view (FOV) of 20×20×25 cm^3, with a readout length of 4 msec. TR/TE = 12/1 msec for the SPGR sequence and TR/TE = 9/1 msec for bSSFP.

We imaged a phantom consisting of 4% agarose gel to simulate cartilage and water to simulate synovial fluid, both with a sodium concentration of 300 mM. The T_2* and T_1 of sodium in the gel were measured to be 2 and 35 msec while the T_2* and T_1 in the water were 16 and 42 msec. We obtained data with the SPGR and bSSFP sequences with flip angles ranging from 20 to 90 degrees. We then calculated the contrast-to-noise ratio (CNR) by measuring the average signal over a hand-selected region of interest (ROI) in the gel, subtracting from it the average signal from an ROI in the fluid, and dividing by the standard deviation of the signal over an ROI in the background noise.

We then obtained *in vivo* sagittal sodium images of the knees of 5 normal volunteers. Subject data was acquired with both SPGR and bSSFP sequences with a flip angle of 90°. We calculated the SNR of cartilage and fluid by measuring the average signal from a hand-selected ROI (in the cartilage or in a vial of water with a sodium concentration of 100 mM) and dividing it by the standard deviation of an ROI over the background noise. We acquired 20 signal averages in every case, holding total readout time constant between the two sequences. Total scan times differed due to a longer TR in SPGR to accommodate the extra spoiler gradient. Scan times were 23 min. for bSSFP and 30 min. for SPGR.

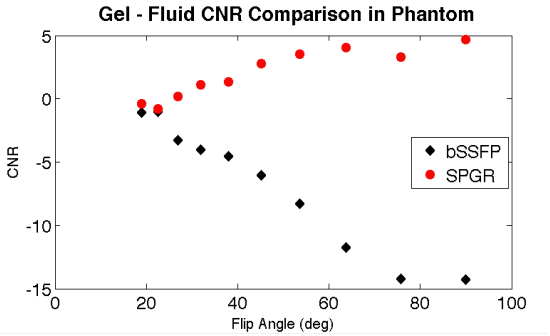

***Fig. 1**: The CNR of the gel over the fluid is maximized with a 90° SPGR acquisition and minimized with a 90° bSSFP.*

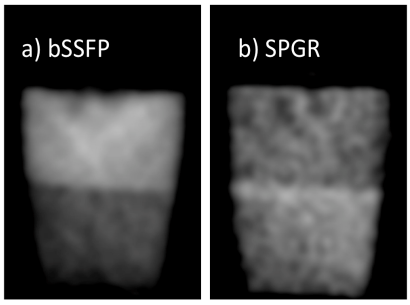

***Fig. 2**: The signal from the fluid is brighter on the bSSFP image, while the contrast is inverted and the gel is brighter on the SPGR image.*

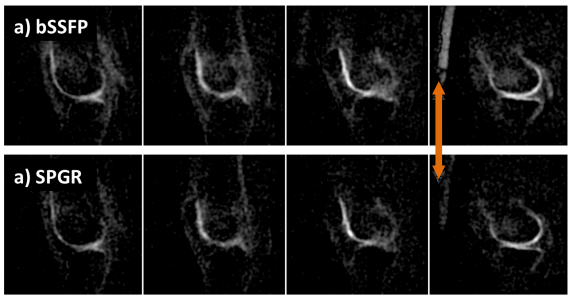

***Fig. 3**: In vivo results acquired with a flip angle of 90° and the same total readout time. The SNR of the cartilage is 20% lower in the SPGR image, while the signal from the vial (marked by the arrow) is attenuated over 66%.*

RESULTS: Fig. 1 shows the measured CNR of the gel and fluid in the phantom. Both the largest (the gel is brighter than the fluid) and the smallest (the fluid is brighter than the gel) CNR occur at the highest flip angle. In the bSSFP sequence with the large flip angle, the fluid is brighter than the gel (the smallest CNR), while SPGR reverses this contrast (shows the largest CNR) at large flip angles.

Fig. 3 shows images from one of the volunteers. Average SNR of the cartilage is 30 ± 6 in the bSSFP sequence, while that of the fluid in the vial is 20 ± 1. For the SPGR sequence cartilage SNR is 26 ± 4, while that of the fluid vial is 8 ± 1. The average cartilage SNR in the SPGR image is 83% ± 9% of the cartilage SNR in the bSSFP image, while the fluid SNR in the SPGR image is 31% ± 4% of the fluid SNR in the bSSFP image. SNR in the fluid vial on the SPGR images was significantly less than on the bSSFP images ($p < .0002$).

CONCLUSION: Given that sodium images usually have low SNR and resolution, it is important to minimize the contribution of fluid to the total signal when trying to quantify the sodium content of cartilage. Using an SPGR acquisition with a large flip angle (in our case 90° for a TR of 12 msec) leads to a higher cartilage/fluid CNR, increasing the confidence that the acquired data represents the sodium in the cartilage only. For cases where total sodium signal is of interest, a bSSFP acquisition with a large flip angle leads to a higher total SNR efficiency.

REFERENCES: [1]A. Bashir *et al., Magn. Reson. Med.,* **41**:857-865, 1999 [2]E. Shapiro *et al., Magn. Reson. Med.,* **47**:284-291, 2002 [3]A. Wheaton *et al., Radiology,* **231**:900-905, 2004 [4]L. Wang *et al., JMRI,* **30**:606-614, 2009 [5]P. Gurney *et al., Magn. Reson. Med.,* **55**:575-582, 2006

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