3T VIPR-SSFP: High Isotropic Resolution MSK Imaging (0.33 mm)

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INTRODUCTION

Methods to produce moderate isotropic resolution (0.7 mm) with multi-echo VIPR at 3T have recently been demonstrated [1]. The multiple echoes were employed with Linear Combination SSFP (LCSSFP) to improve fat/water separation and optimize SNR. As the center frequency is placed midway between the resonant frequencies of fat and water in LCSSFP, greater care must be taken when accounting for phase shifts during the non-Cartesian acquisition, especially at higher resolutions when data acquisition is extended. A simple method to improve the SNR of the desired component, while attenuating the undesired component is presented. Methods necessary to produce 0.33 mm isotropic resolution in a comprehensive knee study are discussed. This represents a more than 8 fold reduction in voxel volume from earlier work [1] without an increase in the 5 minute scan time.

MATERIALS AND METHODS

In LCSSFP, once the center frequency is placed at the midpoint of fat and water (Fig. 1a), *k*-space is sampled twice with the RF transmit phase alternating by π radians each TR in the first pass and remaining constant in the second pass. Linear combinations of these two passes yield both water and fat image volumes. Time for adequate spatial encoding is achieved by placing the undesired component, typically fat, in an alternative stopband (Fig 1a).

Linear combinations of multiple echoes may be used to remove the passband adjacent to fat as it causes increased sensitivity to B0 inhomogeneity. This attenuation was previously achieved using a bulk phase correction [1], which adjusted the phase of the second half-echo to align the phases of points 1 and 3 at the *k*-space origin (Fig. 2). However, this technique causes oscillations at high frequencies (point 2, Fig. 2), which is further exacerbated at high resolutions when data acquisition is extended within each TR. Addressing this problem, the phase accrual of the desired species may be calculated and used to correct both half-echoes on a point-by-point basis (Fig. 3). The result is coherent addition of the desired water signal at all spatial frequencies, as well as further dephasing of the undesired fat signal and attenuation of the adjacent passband (Fig 1b).

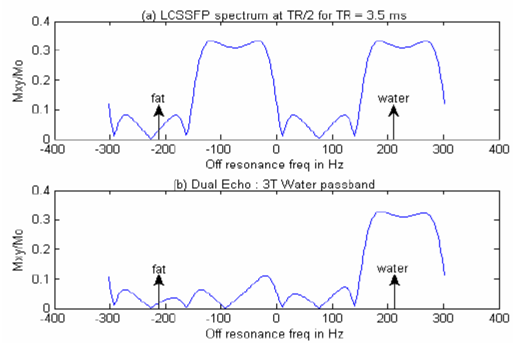

Figure 1 (a) Conventional LCSSFP spectrum with single full echo at TR/2 to obtain fat suppression. **(b)** Spectral response of dual half-echo VIPR-SSFP sequence at 3T for fat suppression.

Gradient calibration, which provides compensation for eddy currents, is achieved by analyzing the phase of a voxel wide test slice while encoding by the readout gradient [2]. As the resolution increases, obtaining adequate signal is more difficult, especially when water and fat destructively interfere within the test slice. We now use a chemical presaturation pulse to saturate water in the test slice, and calibrate solely on fat as it recovers more quickly. Centering a focused 3D cubic shim volume over the joint improves B0 homogeneity throughout relevant structures.

RESULTS AND DISCUSSION

Studies were conducted on a 3T Signa EXCITE HDx scanner (GE Healthcare, Milwaukee, WI) over a 15cm FOV with a 448 x 448 x 448 image matrix in 5 minutes, using an 8 channel phased-array extremity coil. The knee images shown in Fig. 4 give excellent high resolution depiction of cartilage with consistent fat suppression over the joint and high cartilage/fluid and cartilage/bone CNR. Imaging parameters include a BW of ±125 kHz, TR/TE1/TE2 = 3.5/0.6/3.1 ms, and a 15 degree flip angle.

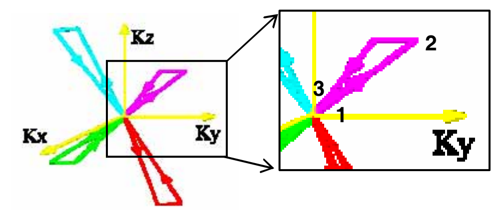

Figure 2 Dual echo VIPR *k*-space trajectories (4 TRs shown). Single TR trajectory begins at 1 and ends at 3.

CONCLUSIONS

0.33 mm isotropic resolution was achieved in a comprehensive knee study, representing a more than 8 fold reduction in voxel volume compared to previous work [1]. A point-by-point phase correction and improved calibration sequence were implemented to allow stable and high quality high resolution images to be acquired.

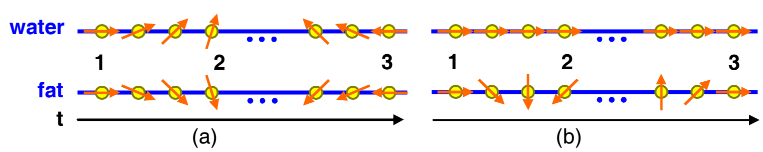

Figure 3 Phase accrual for water and fat spins along the dual echo *k*-space trajectory (Fig. 2). Numbers correspond to trajectory position shown in Fig 2. **(a)** No phase correction. **(b)** Point-by-point phase correction aligns water and further dephases fat.

REFERENCES

1. Jashnani Y, *et al.*, ISMRM 2006, 3607. **2.** Jung Y, *et al.*, *MRM*, in press.

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Figure 4 0.33 mm in-plane resolution images, magnified to show details of cartilage, fluid, and bone interfaces with excellent fat suppression using VIPR-SSFP at 3T. Isotropic resolution provides a possible trade-off between high SNR and partial voluming. The **(a)** axial image is the complex sum of 3 slices with an equivalent slice thickness of 1 mm, while the **(b)** sagittal and **(c)** coronal images average 5 slices with an equivalent slice thickness of 1.5 mm.