Linear Combination SSFP at 3T: Improved spectral response using multiple echoes

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INTRODUCTION

Isotropic high resolution imaging with high contrast of relevant musculoskeletal joint tissues has been implemented using a 3D radial imaging sequence [1] and has demonstrated its ability to assess cartilage clinically at 1.5T [2] The technique, VIPR-SSFP, provides contrast between cartilage and bone by separating fat and water using linear combination steady-state free precession (LCSSFP) [3]. Adapting the technique to 3T imaging is not straight forward because the optimal TR will not allow adequate time for spatial encoding. During each TR in LCSSFP, fat and water develop a relative $(2n+1)\pi$ phase offset. While this TR is only 1.1 ms at 3T when n= 0, possibilities exist to skip a passband with a TR of 3.3 ms when n=1. We demonstrate the feasibility of this technique and describe methods to acquire and properly combine multiple echoes within each TR interval to improve the spectral separation of fat and water and optimize SNR.

MATERIALS AND METHODS

The center frequency is placed at the midpoint of the resonant frequencies of fat and water in LCSSFP. 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. Different linear combinations of these two passes generate both a fat and water image volume. In Fig. 1a, a spectral response for a LCSSFP water volume is illustrated at 3T using a TR of 3.3 ms with a single echo placed at the midpoint between RF pulses. Time for adequate spatial encoding is achieved by placing fat in an alternative stopband instead of the adjacent stopband. A passband adjacent to fat, however, will limit the effectiveness of fat suppression due to B0 inhomogeneity.

LCSSFP is normally acquired with a single echo centered at the point TR/2 to exploit the different phase offsets between the two species on each of the two passes. As fat and water rotate in opposite directions during each TR interval, this difference in phase progression can also be utilized by acquiring multiple echoes. As the time interval between echoes is known, the phase accrual of the desired species can be tracked between echoes and removed during reconstruction. This phase compensation alters the phase of the unwanted species in such a way that the undesired passband between fat and water in Fig. 1a is substantially attenuated in Fig. 1b and Fig. 1c while the desired component adds coherently. With proper alignment of the echoes, the individual echo times can be independent of each other. The specific implementation of a multiple echo sequence we used was s dual half echo VIPR acquisition where two half echoes are obtained each TR, as illustrated in Fig. 2. The two radial lines, similar to a half "bow tie" inherently refocus the transverse magnetization. VIPR-SSFP also acquires data during projection gradient ramps which significantly improves acquisition efficiency.

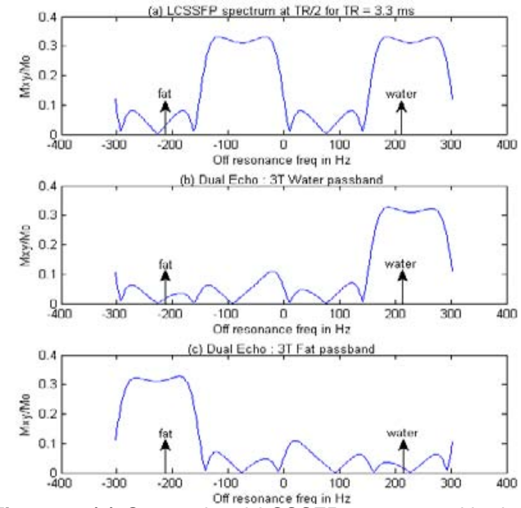


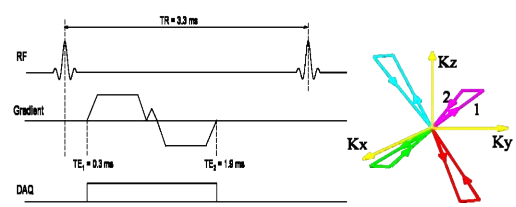
Figure 1. (a) Conventional LCSSFP spectrum with single full echo at TR/2 to obtain fat suppression. Spectral response of dual half echo VIPR-SSFP sequence at 3T for **(b)** fat suppression **(c)** water suppression. TR =3.3 ms, FA = 15 for all cases. TE1/TE2 = 0.3/1.9 ms for VIPR-SSFP

RESULTS AND DISCUSSION

Studies were conducted on a 3T Signa EXCITE HD scanner (GE Healthcare, Milwaukee, WI) over 18 cm FOV with 0.7 mm isotropic resolution in 5 minutes, using a single channel extremity coil. Imaging parameters included BW of ±125 kHz, TR/TE1/TE2 = 3.3/0.3/1.9 ms, and a 15 degree flip angle. The knee images (Fig. 3) shows excellent fat suppression, good CNR between cartilage and fluid and cartilage and bone. When imaging at 1.5T with a four element knee coil with similar resolution parameters, slices were often combined during visualization to generate improved SNR. The improved signal at 3T provides adequate SNR with a single slice.

We soon expect to achieve higher in-plane resolution when an eight channel 3T knee coil becomes available at our site. Higher resolution can be achieved by using some of the unused time between RF pulses in Fig. 2a for spatial encoding. Modifications in the trajectory could also be developed to increase data acquisition efficiency and decrease scan time.

Aligning the phase of dual echoes for the desired species provided a more coherent combination of the desired signal at 1.5T also. Relative to our previous work, this alignment produced a 12% improvement in SNR [2].



(a) (b)

Figure 2 (a) Gradient waveforms & timings. **(b)** k-space trajectories for dual half echo VIPR (4 TRs shown)

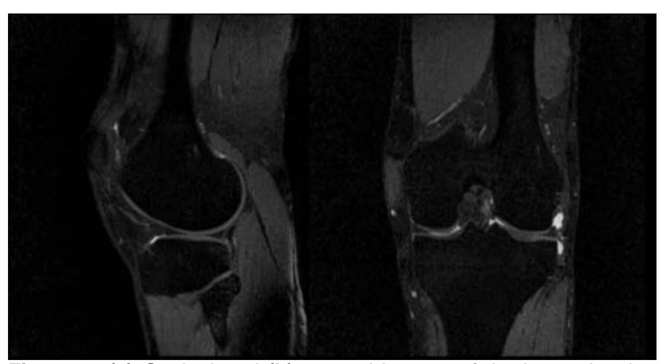


Figure 3. (a) Sagittal and **(b)** coronal images of the knee showing excellent fat suppression with VIPR-SSFP at 3T. The in-plane resolution is 0.7mm by 0.7 mm, with a slice thickness of 0.7 mm. The images were acquired using a single channel extremity coil.

CONCLUSIONS

A multiple echo 3D radial imaging sequence has been adapted to provide fat and water separation using LCSSFP at 3T. The phase progression between echoes is used to remove an unwanted spectral passband and allow increased time for spatial encoding. The results using a single channel coil show significant gains in SNR when compared to 1.5T.

REFERENCES

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