Improved Fat Suppressed SSFP Imaging using 3DPR

P. Gurney[1], B. Hargreaves[1], D. Nishimura[1]
[1]Magnetic Resonance Systems Research Laboratory, Stanford University, Stanford, CA, United States

Introduction

SSFP is a very fast imaging method which provides good tissue contrast and high SNR. Hargreaves et al. [1] have proposed a method for fat suppression which uses the chemical shift difference between fat and water and the refocusing properties of SSFP (and does not require an increase in scan time, as do most other methods [2],[3]). By selecting an appropriate TR, fat and water can be placed in bands of opposite phase. Once the image is formed, each voxel can be determined to be fat or water based on its phase. Since the fat suppression is done on a voxel by voxel basis, this method is sensitive to partial-volume effects which can be a problem at lipid-water interfaces or in tissues which contain a mixture of lipids and fluids. When a 3DPR trajectory is used, however, the prewinder and rewinder half-echoes can be used to provide additional information[3]. Using this information, we can reduce the partial volume effect of the SSFP phase-based fat suppresion.

Theory

Figure 1 shows the relative phase of the water and lipid signals over a full TR which has been chosen to be slightly larger than 4.6ms. Since fat and water have a difference in precession frequency of about 225Hz at 1.5T, it takes approximately 1/225 Hz = 4.6ms for the lipids to make one full phase cycle. Furthermore, the properties of SSFP enforce a difference of pi radians at TE=TR/2. Therefore, at every point during the TR, the relative phase between water and lipid is known. This assumes both a perfect steady-state, and also that there are no species with different chemical shifts. This relative difference should be quite robust for each voxel in the presence of B_o inhomogeneities. If a particular voxel contains a mixture of lipid and water, both components should experience similar inhomogeneities, and the relative phase difference will remain intact.

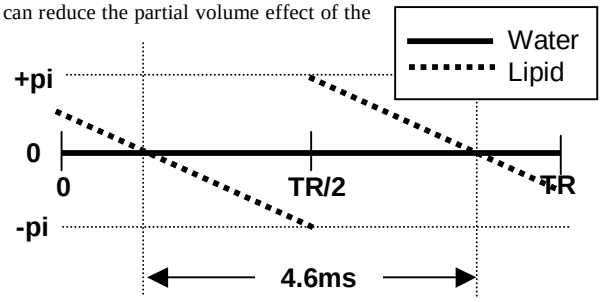

Figure 1 *Relative phase of water and lipids over a TR for an SSFP sequence*

During a full-spoke PR trajectory, each point in k-space is actually traversed at least twice: once during the prewinder or rewinder, and then again during the actual readout, as shown in Fig. 2. These two points can be used along with the known relative phase to solve for an estimate of the magnitudes of the water components for the particular point in k-space (two complex equations, two complex unknowns). For example, at $k_r = 0$, the water component is simply $[M_1+M_4]/2$ (where M_1 is the complex valued k-space sample at (1)). For higher values of k_r, such as at point (2) and point (3), the problem involves solving the complex system:

$$M_2 = M_w - M_f \angle \frac{-2\pi(T_2 - T_4)}{4.6ms}, \qquad M_3 = M_w - M_f \angle \frac{-2\pi(T_3 - T_4)}{4.6ms}$$

for M_w (where T_2 is the time at which point (2) was obtained in ms from the RF excitation). This problem becomes less well-conditioned with increasing kr, which will result in a noisier looking image, but this can be mitigated by regularization.

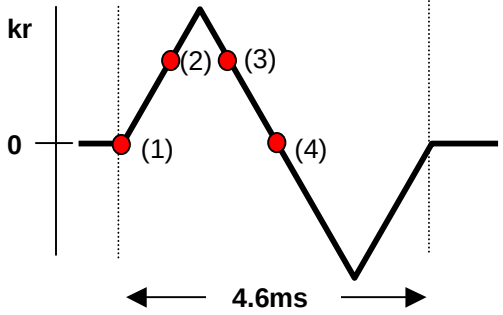

Figure 2 *PR k-space trajectory as a function of time. Each point in k-space is sampled at two different times.*

Results

The method was successfully implemented on a GE LX 1.5T scanner. The received data for the prewinder, top half of the readout, bottom half of the readout, and the rewinder were gridded separately. The estimate of the water component was then solved for separately using the gridded data for the first two half-echoes, followed by a separate estimate for the second two half-echoes. These two estimates were then added together and Fourier transformed to obtain the water image. Figure 3 shows a comparison of an image obtained with 15x15x15cm^3 FOV, 0.8mm nominal resolution in 30,000 interleaves (undersampled by a factor of about 2, 180s scan time), a flip angle of 55 degrees and a TR = 6ms. The estimated water appears noisier than the original image, but also includes somewhat finer detail in very small vessels embedded in lipid (dashed arrow). The femoral cartilage is noticeably thicker (solid arrow), presumably because it is not affected by the partial volume effect at its edges.

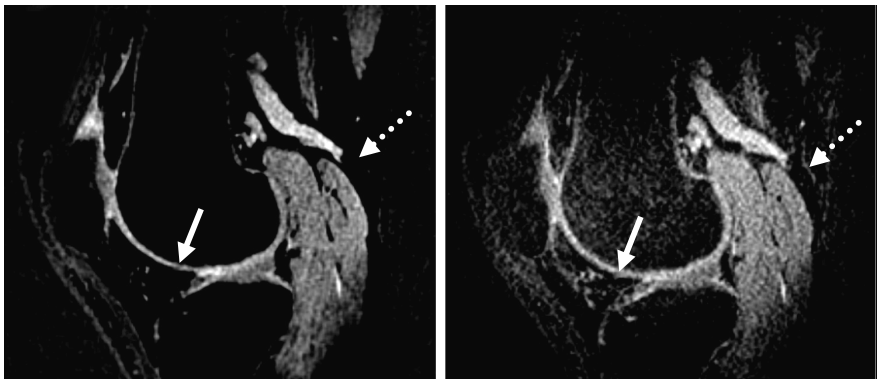

Figure 3 *Images of the knee (a) using only the readout portion of PR data and simple phase-based fat suppression, (b) using both the rewinder, prewinder and readout portion of PR data and water component estimation.*

Conclusion

When using the PR imaging trajectory with SSFP, the extra information available during the prewinder and rewinder can be used to extract an estimate of the water image which is less prone to partial-volume effects than the original phase-based approach and does not increase the scan time. The amount of noise added by this process can be controlled by adjusting the regularization parameters of the solution.

References:

[1] Hargreaves *et al*. MRM 50(1):210-213 2003.
[2] Vasanawala *et al*. MRM 43(1):82-90, 2000.
[3] Scheffler, *et al*. MRM 45(6):1075-1080, 2001.
[4] Brodsky *et al*., ISMRM Toronto #322, July, 2003.