Water-Fat Separated Phase-Cycled SSFP by Field Mapping Using Magnitude Images

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Introduction

Banding artifacts and strong fat signals are two major obstacles for SSFP. Though phase-cycling or frequency-shifting have been shown to be effective in removing the banding artifacts [1], fat suppression remains difficult, particularly at low- and mid-field strengths. Recently, single quadrature Dixon (SQD) methods have been introduced for water-fat separation with SSFP [2, 3] in the presence of field inhomogeneities. Field inhomogeneities are estimated using the phase information from the isolated images, but such phase-based field mapping methods are susceptible to contamination by chemical shifts. In this study, field inhomogeneity maps are generated from magnitude images as an attempt to avoiding chemical shift contamination. Field maps so generated are used to phase-correct the isolated images and to finally construct the water and fat separated images.

Theory

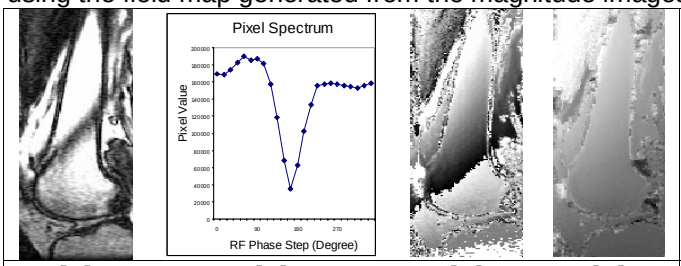
In phase-cycled SSFP, multiple data sets are acquired with linear RF phase shift of different increments. By combining the signals, images of explicit echo formation pathways can be isolated [1]. In SQD SSFP, TR and TE are set according to $TR = 2TE = 1/(2\Delta f)$, where Δf is the frequency separation between water and fat. Two isolated images are used in which water and fat signals have different phase relationship: $I_0 = (W_0 + iF_0)e^{i\phi}$ and $I_{-1} = (W_{-1} - iF_{-1})e^{-i\phi}$ with ϕ being the field inhomogeneity angle given by $\phi = \gamma \Delta B_0 TR$. Also, pixel intensities of phase-cycled SSFP images depend on the phase increment. The intensity is minimal when the phase increment matches the spin precession angle during each TR [4]. Therefore, by analyzing the pixel intensities vs. phase increments, a map of spin precession angles can be generated. Doubling the spin precession angles sets the water and fat difference to 2π under the SQD conditions. Since the wrapped precession angles are related to ΔB_0 by $2\psi = 2\phi \pm n2\pi = 2\gamma \Delta B_0 TR \pm n2\pi$, a ΔB_0 map can be generated by un-wrapping the 2ψ map in which chemical shift effects are removed. After correcting for the effects of field inhomogeneities while preserving the chemical shift information, water and fat signals are properly focused into the real part or the imaginary part, respectively, of I_0 and I_{-1}. It then becomes simple arithmetic operation to construct water and fat separated images.

Experiments

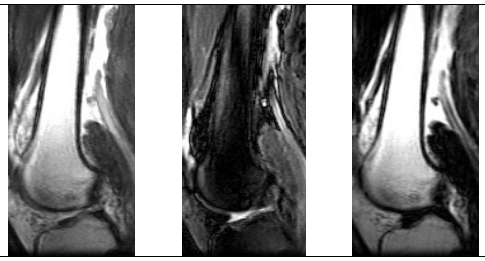
A 3D phase-cycled SSFP sequence was implemented on an OpArt ULTRA scanner (Toshiba Medical Systems Co., Japan) operating at 0.35 T, with TR = 10 ms and TE = 5 ms. Human knee images were acquired with RF phase-cycling in steps covering the range between –π and +π. Data were analyzed on an SGI O2 work station (Mountain View, CA).

Results

Shown in Fig. 1 is [A] one of the phase-cycled SSFP magnitude images of a volunteer human knee; [B] intensity of a selected pixel vs. phase increments; [C] a precession angle map generated from the minima positions, and [D] a field map generated by un-wrapping the angle map. Shown in Fig. 2 are [A] SSFP image, [B] water image and [C] fat image separated using the field map generated from the magnitude images.



[A] [B] [C] [D]
Fig. 1 Phase-cycled SSFP of a human knee.



[A] [B] [C]
Fig. 2 Water-fat separated SSFP images.

Reference

[1] Zur Y et al., Magn. Reson. Med. 16:444-459 (1990). [2] Miyoshi M et al., Proc 11th ISMRM, 981 (2003).
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