Magnetic Field Mapping Using Magnitude Images of Phase-Cycled or Frequency-Shifted SSFP

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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. In most cases, information about the field inhomogeneities is required. Since B_0 during SSFP can be significantly affected by sequence-induced changes, it is preferable to obtain field maps from the image data itself. Such attempts have recently been made using isolated signals [2, 3], but the phase-based algorithms failed to rid the interference from chemical shifts. In this work, we introduce a method for field mapping during SSFP by analyzing pixel intensities of phase-cycled or frequency-shifted SSFP magnitude images.

Theory

Shown in Fig. 1 is a spectral response of the SSFP signal. Signal intensity is minimal when the spin precession frequency matches the RF frequency. Therefore by finding the minima of a series of image intensities acquired at a range of RF frequencies covering the spectrum, the spin precession angle, ϕ, can be determined for each image pixel. Since ϕ is related to B_0 by $\phi = \gamma \Delta B_0 TR \pm n2\pi$, a ΔB_0 map can be generated by un-wrapping the ϕ map.

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 $-\pi$ and $+\pi$. Signal minimum among the images of different phase increments was located using a three-point quadratic solution. Spin precession angle was set to the RF phase increment that corresponds to the position of the minimum.

Results

Shown in Fig. 2 is [A] one of the phase-cycled SSFP 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. 3 are angle maps generated from different numbers of RF phase increments.

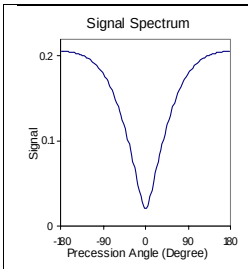
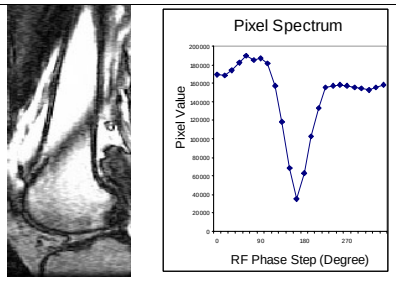
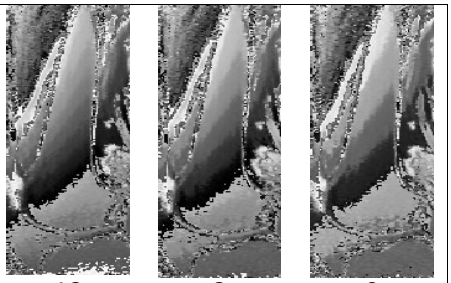


Fig. 1 SSFP Spectrum



[A] [B] [C] [D]

Fig. 2 Phase-Cycled SSFP Signals of Knee



12 8 6

Fig. 3 Precession Angle Map

Conclusion

By analyzing pixel intensities as a function of phase increments in phase-cycled or frequency-shifted SSFP sequences, magnetic field inhomogeneity maps can be generated.

Reference

[1] Zur Y et al., Magn. Reson. Med. 16:444-459 (1990). [2] Miyoshi M et al., Proc 11th ISMRM, 981 (2003).
[3] Zhang W et al., Proc 12th ISMRM, 2684 (2004).