Darkband SSFP

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Introduction

Very low flip angles in steady-state free precession (SSFP) sequences produce a highly frequency-selective steady state, characteristically different from that of typical large flip angles. This frequency selectivity may be used for metabolic mapping. Due to the small flip angles the sequence offers a new approach to SAR problems at high fields.

Methods

Typical flip angles in SSFP are in the range of 20-80˚. The selection profile shows wide passbands of high signal and narrow darkbands, where the magnetization is dispersed. At flip angle ranges of 0.05-3˚ the signal relationship is reversed, with high signal generated in the darkbands (Figure 1) [1]. The signal peak in the darkband has an extremely small full-width-at-half-maximum (FWHM) on the order of 1/T2 and reaches the signal level of SSFP at the optimal flip angle.

B0-inhomogeneity requires that several of these images are acquired to reconstruct a frequency interval. The separation of M_x from M_y raises the frequency selectivity and suppression of spins from off-resonance frequencies substantially. This is achieved by acquiring a phase-map, which is recorded with an equivalent darkband SSFP sequence but at a frequency shifted by +50 Hz towards the water peak. The phase of this image corresponds to the phase induced by differences of the transmit and receive fields in the sample.

A summation technique where the frequency profiles are not simply summed, but two images from frequencies more than 1/T2 apart are subtracted from another, and then the absolute values are looked at, allows for further reduction of the off-resonance-signal.

Thereby a suppression of water to signal levels below that of metabolites of in-vivo concentrations without any specific suppression pulse techniques is achievable.

Phantom and in-vivo measurements were performed on a 3T Intera whole body MR system (Philips Medical Systems, Best, The Netherlands). A 3-dimensional SSFP sequence was applied without phase alternation. Following parameters were used: matrix size 64x64, TR = 2.45ms, FOV 200x400x400mm^3, 260s acquisition time for each of the twelve images for Figure 2 and TR = 2.49ms, FOV 300x48x300mm^3 and 201s acquisition time for each of the twenty images used in Figure 3. All images were cropped and zero-filled. The flip angle was optimized for highest signal in the darkband.

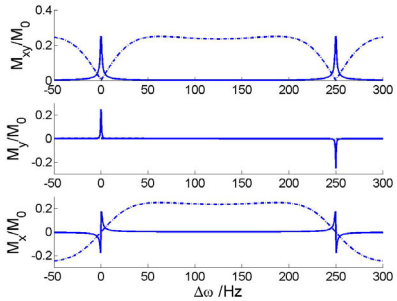

Figure 1: Steady-state profiles at t = TE. Parameters: TR = 4ms, TE = 2ms, T1 = 2s, T2 = 0.5s. dotted line: standard SSFP with α = 39˚, solid line: darkband SSFP with α = 0.23˚

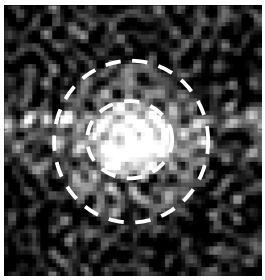

Figure 2: Image of a beaker phantom with an inner sphere containing a 5 mmol/l solution of creatine. The SNR of the inner sphere is 6.4 and the CNR against the water beaker is 2.0.

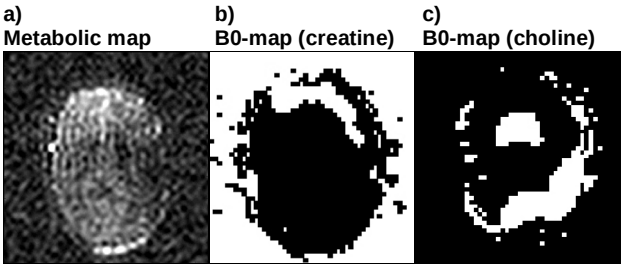

Figure 3: The upper region in (a) shows signal from creatine, whereas the lower signal is from choline. The signal is detected from only parts of the brain due to B0-inhomogeneity and corresponds to the field-maps of the creatine (b) and choline (c) resonances, respectively.

Results

Images of a spherical phantom filled with 5mmol/l creatine placed in a beaker filled with water were obtained with the described sequence (Figure 2). For reconstruction twelve consecutive measurements each shifted by a frequency offset of 1Hz were used. Images of a human brain were recorded in a similar fashion with 20 consecutive measurements (Figure 3). The signal from the inner sphere of Figure 2 is clearly higher than the surrounding water beaker.

The in-vivo image shows signal in two areas of the brain. The upper area is creatine, as illustrated by the field-map, where 20 Hz around the expected recorded area is shown bright in the map (Figure 3b). The lower area is choline, which appears in the same image because the field-inhomogeneity over the brain is larger than the distance between the two peaks. The field map of choline roughly fits to the intense lower area of the brain (Figure 3c).

Discussion

The phantom experiment clearly demonstrates that the required high suppression levels can be reached. If a wider frequency interval is acquired with more images, the suppression can be substantially increased with a higher sign-alternate summation factor. The in-vivo experiment is a preliminary result, but the good agreement with the field-map shows that the signal of the metabolites can be made out.

Conclusion

By applying very small flip angles a high signal level comparable to conventional SSFP can be achieved at very low SAR. The high frequency-selectivity of the presented technique shows promise for chemical-shift imaging. Further work is warranted to reduce the acquisition duration to times acceptable in a clinical environment.

References

[1] Freeman R, et al., JMR 1971;**4**:366-383