An automatic real-time feedback calibration of RF phase cycling by off-resonance weighted imaging sequence

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Introduction

Balanced steady-state free precession (bSSFP) has been shown useful in many clinical applications. However, the well-known banding artifact of bSSFP makes it inappropriate to area with severe field inhomogeneity. This study aims to adjust RF phase cycling (β) to avoid banding artifacts on the tissue structure of interest. We proposed to obtain the optimal RF phase cycling by combing a new pulse sequence sensitive to off-resonance effect and an automatic real-time (RT) feedback optimization system [1]. It is potential to serve as a pre-scan for bSSFP imaging or blood oxygenation sensitive SSFP (BOSS) fMRI [2].

Material and Methods

The pulse sequence is displayed in Fig. 1. The pulse sequence has two major parts. First, all gradients in slice, phase, and readout direction are balanced to keep the steady-state of longitudinal and transverse magnetization after a RF with flip angle of α. Second, a RF with flip angle of –α is applied to restore magnetization back to the longitudinal axis. A crusher gradient in slice direction spoils residue transverse magnetization. Using this sequence, the steady-state signal decreases positively in conjunction with off-resonance frequency, and the sequence was termed as off-resonance weighted imaging (OWI). This study utilized signal intensity of OWI as the "cost function" of a Brent-method-based optimization system. The optimization goal is to find an optimal β which maximized the signal intensity of OWI. The automatic real-time feedback optimization method contains three major procedures: immediate image transfer from MR scanner to personal computer, optimization of β, and automatic on-line feedback control of current scan parameter. When ROI-based optimization is desired, a pre-scan image with β of zero is applied for manual ROI selection before performing the optimization of β.

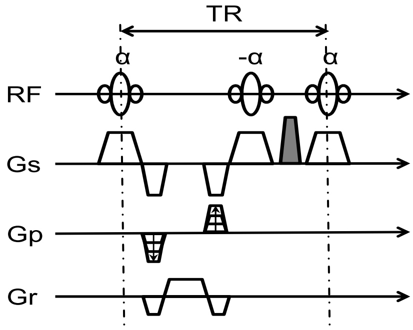

Figure 1. The pulse sequence of off-resonance weighted imaging (OWI).

All experiments were performed on a 3T whole-body MR system (Siemens, Tim Trio, Germany) equipped with an 32-channel head coil. Two volunteers participated in the human brain experiments after providing institutionally approved consent. Sweep scans of three types of sequences, OWI, BOSS (bSSFP without RF alternation, proposed by Miller et al. for fMRI application [2]), and conventional bSSFP were performed with parameters (TR/TE: 4ms/2ms matrix: 128×128; flip angle: OWI:10˚, BOSS: 5˚, and conventional bSSFP: 70˚, β: -180˚ to 180˚ with step size of 10˚). For the real-time optimization, the acquisition started with three initial βs (-50˚, 0˚, 50˚) and the convergence criterion for Brent's optimization [1] was set to 2˚. The optimization goal is to maximize average signal intensity of an ROI that were manually selected around occipital lobe.

Results

Figure 2 displays the average signal intensity of the ROI in the sweep-scan images. The bSSFP curve (Fig.2, black square) displays a plateau and sharp dips at about -150 degree. The signal drop corresponds to banding artifacts around occipital lobe (Fig.3c). When β is 20˚ (Fig.2, green line), there is a peak in OWI curve (Fig.2, blue circle), which is roughly at the central of the plateau of bSSFP curve. The BOSS curve (Fig.2, red triangle) shows double peaks when β is near 20˚. The central of the two corresponding βs is also about 20˚. Figure 3 presents images acquired using β of -150˚ (a,b,c) and 20˚ (d,e,f), respectively. The images acquired using β of 20˚ exhibit higher signal around the occipital lobe. Figure 4 obtained from another volunteer shows OWI sweep scan (blue circle) and the progress of real-time feedback optimization based on OWI (red triangle). The β optimization reached convergence criterion after 10 iteration loops. The optimal β obtained by real-time optimization method is 40.64˚, which is close to the optimal β obtained by the sweep scan (β = 40˚).

Discussion and Conclusions

In our results, both OWI and BOSS are sensitive to the off-resonance effect and are therefore suitable for finding optimal β of bSSFP by sweep scans. BOSS sweep-scan curve exhibits double peaks and the desired β appears between the two peaks. OWI sweep-scan curve has a single peak. Hence, OWI is more appropriate for real-time feedback optimization based on Brent's method. Compared to the discrete global search using the sweep scan (step size = 10˚), the real-time optimization requires fewer measurements (10 versus 37) and potentially improves the precision of β using convergence criterion of 2˚. Our preliminary results demonstrated the efficiency of real-time β optimization for BOSS and conventional bSSFP in brain imaging. We therefore conclude that this method is potentially useful to serve as a pre-scan to improve β calibration, especially for a specific tissue structure of interest.

Reference

[1] Tang YW et al., NeuroImage 2011;55:1587 [2]Miller KL et al., Magn Reson Med. 2003 Oct;50(4):675-83

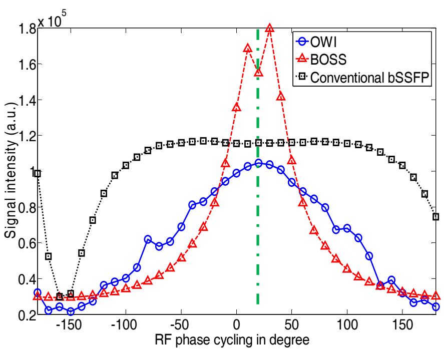

Fig. 2 Phase-cycling curves of OWI, BOSS and bSSFP (subject #1). The peak in OWI detects the identical β corresponding to center of high signal bands both in BOSS and conventional bSSFP.

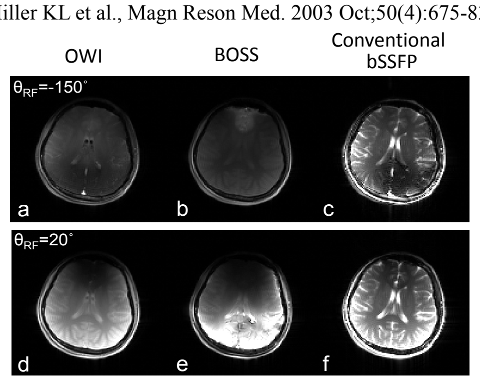

Fig. 3 The effect of β in three types of imaging (subject #1). Using θ_{RF} of -150˚, the signal in occipital lobe (a:OWI, b:BOSS, c:bSSFP) is relatively low. Using β of 20˚, the signal of occipital lobe (a:OWI, b:BOSS, c:bSSFP) is improved.

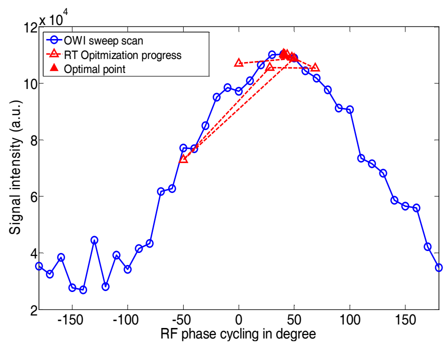

Fig. 4 Real-time optimization utilizes ten iterations for detecting optimal β that is close to the peak in OWI sweep scan (subject #2).