Real-time compensation for respiratory-induced frequency shift in balanced SSFP by RF phase feed back

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Introduction

In functional MRI, respiration induced B_0 field fluctuation has been well studied [1,2]. This B_0 fluctuation causes a magnetization profile shift in balanced SSFP since the magnetization profile is sensitive to off resonance frequency. In Blood Oxygenation Sensitive Steady State (BOSS)[3], which is based on balanced SSFP with a small flip angle, the profile shift means a change of activation band location which results in contrast-noise-ratio (CNR) degradation. Compensating for this fluctuation significantly improves the performance of the BOSS technique. Here, we present a novel method to compensate for this respiration induced B_0 field fluctuation in balanced SSFP by using real-time feedback to modify the phase of the RF excitation pulse.

Background

BOLD fMRI detects changes in blood oxygenation based on the frequency shift of deoxyhemoglobin. BOSS uses the sharp phase transition of balanced SSFP to achieve higher functional contrast than standard BOLD. Respiration induced B_0 field fluctuation is uniform across an axial slice [2] and can be measured from phase changes in the free induction decay (FID). This rotation can be compensated by changing the RF phase in real time.

Methods

Imaging was done on a 1.5T GE EXCITE using a standard head coil. A real time system [4] developed at Stanford was used to estimate the frequency shift from respiration and to update the RF phase change in real time. One experienced subject was instructed to breath regularly and slowly. A lower brain axial slice was scanned with a balanced SSFP technique. The imaging parameters were 24 cm FOV, 5 mm slice thickness, 4° flip angle and 7.8 ms TR. A 2 ms FID was measured. B_0 off-resonance was calculated for every TR and averaged over 16 TRs to increase the SNR of the phase measurement. The first 15 seconds of each experiment were averaged and removed from each FID to eliminate distortions from other factors including eddy currents. The mean values of the front half of FID phases (Φ_F) and the latter of half FID phases (Φ_L) were calculated and the frequency offset (ω) was estimated by ($\Phi_F - \Phi_L$)/Δt. After 30 sec, the real-time feedback loop was activated to compensate for B_0 field changes. The RF was phase-cycled by adding an offset phase ($\Phi = \omega \times$ TR) that was updated every 16 TRs (125 msec). The total scan time was one minute (30 sec without correction, 30 sec with correction).

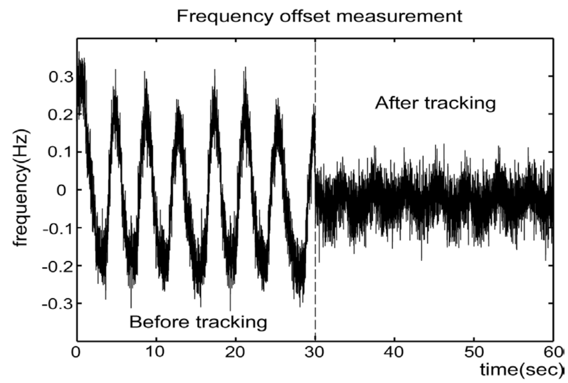

Fig 1. Frequency offset measurement from FID
Note: Frequency offset has reduced by a factor of nine
The phase compensation started after 30 sec

Results

The obtained B_0 offset frequency estimation is shown in Fig. 1. The frequency spectra before and after the compensation are shown separately in Fig. 2. A maximum 0.5 Hz frequency shift was measured. This measurement shows a good agreement with the results observed by Noll, et al [1]. After the compensation, the respiration frequency shift was reduced by a factor of nine.

Discussion and Conclusions

The respiration induced B_0 field fluctuation in balanced SSFP can be compensated by the real-time RF phase feed back and RF phase cycling. The resulting stabilized balanced SSFP magnetization profile reduces respiration noise and thus increases the CNR in BOSS fMRI. Phase offset can be more accurately measured by filtering the high frequency then averaging FIDs will not be necessary. Steady state disturbance due to non-linear phase changes was minimal with maximum a 0.003 degrees of phase change in one TR [5]. This method will provide an even greater improvement at higher fields since the respiration-induced offset frequency is greater.

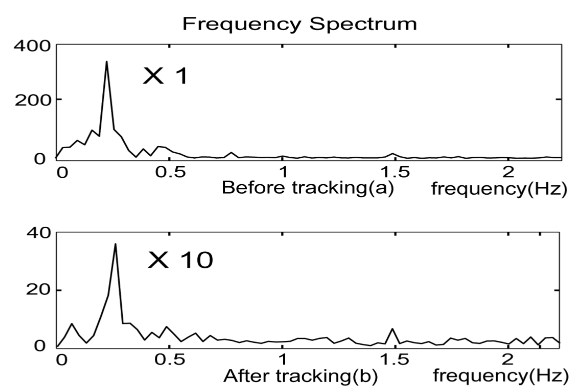

Fig 2. (a) Frequency spectrum of before frequency tracking, (b) after frequency tracking
Note: the scale is ten times bigger in (b)

References

[1] Noll, et al. IEEE Int Conf Image Process, Austin 40 (1994)
[2] Moortele, et al. MRM 47:888 (2002)
[3] Miller, et al. MRM 50:675 (2003)
[4] Santos, et al. IEEE EMBS 26th , 1048 (2004)
[5] Foxall. MRM 48:502 (2002)