A Novel BOLD-Sensitive SSFP Technique with Applications for Cardiac Imaging

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Introduction: Non-invasive assessment of myocardial ischemia is challenging. Because the BOLD (Blood Oxygen Level Dependent) effect mainly relies on endogenous contrast (deoxyhemoglobin) to differentiate ischemic from non-ischemic tissue, BOLD imaging has the potential to directly assess myocardial oxygenation.

Traditionally, BOLD imaging has used T2*-weighted sequences (such as Echo Planar Imaging (EPI)), but many of these are hampered by problems with image quality and SNR. Steady-state Free Precession (SSFP) typically achieves excellent SNR and image quality. Additionally, it has been demonstrated that a steady-state SSFP sequence is BOLD-sensitive (1). However, a direct implementation of steady-state BOLD-SSFP for cardiac imaging is complicated, because spins will be continually moving in and out of the imaging plane. Therefore most spins in the myocardium will not have been excited by a sufficiently large number of pulses prior to acquisition and will not be in steady-state. Modifications to a conventional SSFP sequence must be made before steady-state SSFP is feasible for cardiac BOLD imaging.

Purpose: To develop a novel steady-state BOLD-sensitive SSFP sequence which can potentially compensate for cardiac motion, and to compare its behavior to T2*-weighted EPI.

Methods: A modified SSFP sequence was designed with the goal of obtaining images with a strong T_2-weighted component. Before each acquisition period, a train of SSFP dummies designed to excite a 7 cm slice (centered on the acquisition slice) were played out for 850 ms. Next, a flip back pulse was applied to "store" the transverse magnetization on the longitudinal axis. This was followed by a gradient spoiling, then slice-selective (10 mm) SSFP dummies and acquisition.

All studies were performed on a 1.5T Siemens Avanto. As a model of cardiac ischemia, a pressure cuff was placed on the upper arm of 11 volunteers. Each underwent two seven minute scans of their forearm, once with steady-state SSFP and once with T_2*-weighted EPI. During each scan, the cuff was inflated to 170 mmHg for the middle three minutes to produce ischemia, followed by a period of reactive hyperemia after the cuff was deflated.

To evaluate BOLD sensitivity, the mean signal for the two sequences was calculated over four data points for three time periods: 48–72 s (baseline), 240–264 s (ischemia), and 328–352 s (hyperemia). Regions-of-interest (ROI) were drawn in the arm muscle for each data set using as large an ROI as possible while excluding vessels, bone, and artifacts. The average signal was calculated for each of these periods and was used to determine the percent change from rest to ischemia and from rest to hyperemia. A matched pairs t-test was used to determine if the signal change was statistically significant (α=0.05).

Sequence parameters for both sequences were FOV=263x350 mm^2; matrix=119x256; 8 s/image. Segmented acquisition was repeated once per second. Sequence parameters specific to EPI: train length = 29; echo spacing = 0.9 ms; flip angle = 90^o; acquisition began 35 ms after excitation. For SSFP: TR/TE/flip angle = 5.5 ms/2.75 ms/60^o; 15 lines/acquisition period.

Results: Mean percent signal changes±standard error for EPI were 2.7±0.7 (baseline vs. ischemia) and 4.8±0.6 (baseline vs. reactive hyperemia). Mean percent signal changes for SSFP were 2.4±0.4 (baseline vs. ischemia) and 2.1±0.2 (baseline vs. reactive hyperemia). All signal changes were statistically significant ($p<0.05$). Signal curves for both EPI and SSFP followed a trajectory seen previously for this type of model (Figure).

Conclusion: The new steady-state SSFP sequence has sufficient BOLD sensitivity to detect signal changes at 1.5 T in an arm cuff model of ischemia/hyperemia, while maintaining a sequence structure suitable for cardiac imaging. SSFP shows promise for detecting oxygen changes in the heart.

References

1. Dharmakumar R et al. *Magn Reson Med* 2004;53: 574-83.

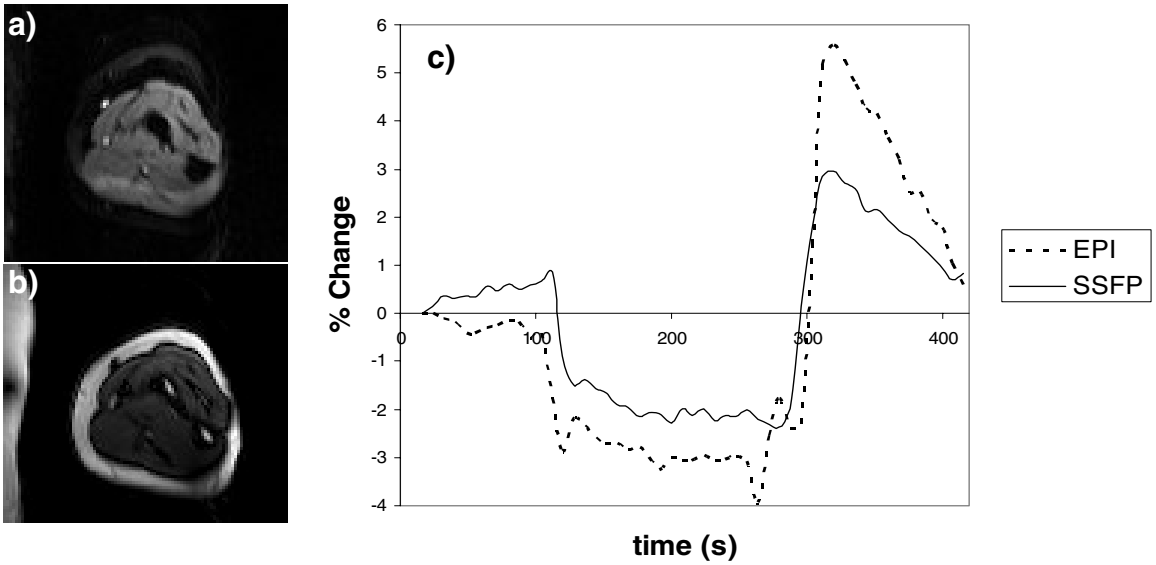

Figure: Sample cross-sections of the forearm before cuff inflation, scanned using a) EPI and b) steady-state SSFP. Typical EPI distortions are seen in a). c) Percent change (compared to the first measurement) vs. time for the mean of each time point for EPI (dashed line) and SSFP (solid line). The pressure cuff was inflated at 120 s, and deflated at 300 s.