# A new SSFP BOLD Sequence for the Detection of Myocardial Ischemia in Patients: Feasibility Study

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**Introduction:** Non-invasive assessment of myocardial ischemia is challenging. Most current techniques base their diagnosis on indirect measurements, ranging from functional abnormalities to the perfusion of injected tracers. 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, many BOLD sequences have seen limited cardiac applications due to low SNR and prevalent image artifacts. Steady-state Free Precession (SSFP) has been widely used for functional cardiac imaging because of its ability to achieve high SNR with excellent image quality. Recently Dharmakumar et al. demonstrated that a balanced SSFP sequence in the steady-state could also be used for cardiac BOLD. However, a direct translation of this technique into the heart is difficult. Achieving and maintaining spins in the steady-state in the heart using slice-selective acquisition is difficult because cardiac motion will be continually moving these spins in and out of the imaging plane. Therefore modifications to the steady-state SSFP technique must be made before it can be applied for cardiac BOLD imaging.

**Purpose:** To demonstrate the feasibility of using a SSFP imaging sequence in the steady-state for detecting myocardial ischemia in patients with cardiac disease.

**Methods:** Four patients were enrolled in this study after being referred for a clinical cardiac MR scan. All the patients had recently undergone a SPECT Thallium stress test using a conventional scanner (Phillips Forte). All MR imaging was performed using a 1.5 T Siemens Avanto System (Siemens Medical Solutions, Erlangen, Germany).

A SSFP BOLD sequence was designed with the goal of imaging myocardium near signal steady-state to guarantee strong $T_2$-weighted imaging. The sequence was electrocardiographically (ECG) triggered and data was acquired in a segmented fashion. Before each acquisition period, a train of pulses was applied during the trigger delay period. These pulses were unspoiled to generate a SSFP-like contrast and had a repetition time of 8 ms to emphasize the T2-component of the signal. To compensate for cardiac motion, each of the preparation pulses excited a 7 cm slice (centered on the acquired slice). At the end of this pulse train, a flip back pulse (also with a 7 cm slice thickness) was applied to "store" the longitudinal magnetization on the z axis. This was followed by a gradient spoiler that destroyed any remaining transverse magnetization. A series of eight slice-selective SSFP dummies were then applied to reduce signal oscillations, followed by slice-selective acquisition with a thin slice (10 mm).

Patients were first scanned at baseline using the SSFP BOLD technique. Three slices were collected in a short-axis orientation (basal, mid, apex). Then the patients were infused with a pharmacological stress agent, adenosine. After approximately two minutes of infusion, the same three slices were collected (stress images). After obtaining stress images, conventional gadolinium-based contrast agent was injected and after a minimum of 5 minutes, late enhancement (LE) images of the entire left ventricle were obtained using standard sequences to detect myocardial infarction.

Data were analyzed using a clinically validated software package (cmr[42], The Circle Corporation, Ltd., Calgary, Canada). Each slice for each modality was divided into myocardial segments for analysis (6 segments for basal and mid-ventricular slices, 4 segments for the apical slice). Signal intensity was measured for each segment at rest and stress for SSFP BOLD. The corresponding LE images were segmented in a similar fashion, and segments which showed LE over 50% or more of their area were considered positive for myocardial infarction and were not analyzed for SSFP BOLD changes.

Using accepted guidelines, segments in the SPECT images which saw a 7% or greater decrease in signal intensity (rest to stress) were considered positive for myocardial ischemia. Less than a 7% decrease or an increase in signal were considered negative. Based on previously published results, a decrease in signal intensity of 1.2% or greater in a segment under MRI was considered positive for ischemia; less than a 1.2% decrease or an increase was considered negative.

**Results:** A typical result is shown in the Figure. Excluding segments which showed LE, a total of 46 segments were analyzed. Treating nuclear medicine as the gold standard, SSFP BOLD showed a sensitivity of 62% and a specificity of 72%. The positive predictive value was calculated to be 65%, while the negative predictive value was calculated to be 69%.

**Discussion and Conclusion:** SSFP BOLD imaging in patients is feasible and shows promise as a technique to detect ischemic changes in the heart.. Image quality was sufficient in all segments and segments were only excluded based on the presence of LE. Sensitivity and specificity may be artificially deflated due to misregistration with the SPECT images. This is a limitation that should be addressed in future studies by comparing both modalities to an invasive gold standard such as X-ray angiography.

**Figure:** SSFP BOLD images from a mid-ventricular slice acquired before (left) and during (right) infusion of adenosine. The posterior septum (arrow) shows a regional decrease in signal, which extends into the anterior septum and corresponds to a regional decrease on the SPECT scan.