

# Cardiac Phase-Resolved 3D SSFP Myocardial BOLD Imaging in Canines with Coronary Artery Stenosis

X. Zhou<sup>1</sup>, S. Zuehlsdorff<sup>2</sup>, S. Shah<sup>2</sup>, R. Tang<sup>1</sup>, R. Klein<sup>1</sup>, D. Li<sup>1</sup>, and R. Dharmakumar<sup>1</sup>

<sup>1</sup>Department of Radiology, Northwestern University, Chicago, IL, United States, <sup>2</sup>Siemens MED US, Chicago, IL, United States

**Introduction:** Recent studies have shown that regional myocardial oxygenation changes due to coronary artery stenosis may be detected with 2D steady-state free precession (SSFP) blood-oxygen level-dependent (BOLD) imaging [1]. One potential limitation of the 2D SSFP BOLD approach is the disruption of steady-state myocardial signal due to through-plane cardiac motion in the presence of slice-selective excitation [2]. A consequence of breaking the dynamic steady state of the SSFP BOLD signal is that it may lead to a reduction in myocardial oxygen sensitivity. Slab-selective excitations (3D) may be able to better preserve the steady-state features of the signal than slice-selective (2D) excitations. The purpose of this work is to investigate whether there are any observable differences in myocardial BOLD contrast between 2D and 3D approaches and to explore the utility of 3D SSFP BOLD imaging using a canine model with controllable coronary artery stenosis.

**Methods:** Four dogs were operated on and studied under institutional approval. For each animal, following thoracotomy, a hydraulic occluder was placed around the left circumflex coronary artery (LCX) to induce reversible LCX stenoses. A Doppler flow probe was placed distal to the occluder to assess the fidelity of the stenosis during the MRI studies. Following recovery (1 week), animals were sedated, ventilated and placed on the scanner table (1.5T Siemens Espree). ECG-gated and multiple breath-held 2D and 3D cine SSFP sequences were prescribed under basal and adenosine stress with and without LCX stenosis over the left ventricle (LV). Typically 2-3 stenosis levels (mild to severe, on the basis of Doppler flow) were assessed. Each animal was studied 2 to 3 times. Scan parameters for 2D acquisitions: in-plane resolution=1.2mm x 1.2mm, slice thickness=5mm (3 slices, 5mm gap), iPAT factor=2, TR/TE = 4.7/2.35ms, flip Angle = 70°; 3D acquisitions were the same, except for slab thickness = 30mm (6 partitions). Both 2D and 3D short-axis images were acquired with center slice positioned over the mid-left ventricle. TR and segments/cardiac phase were adjusted to achieve the optimal temporal resolution (10 ms to 20 ms) and to minimize motion and flow artifacts in 2D and 3D acquisitions while maximizing oxygen sensitivity. For simplicity only end-diastolic images were analyzed. From the matched 2D and 3D image slices, Regional SSFP BOLD Contrast, defined as  $[I_{LAD} - I_{LCX}] / I_{LAD}$ , was computed; where,  $I_{LAD}$  and  $I_{LCX}$  are the average SSFP signal intensities measured from the left anterior descending artery (LAD) and LCX myocardial territories, respectively. Contrast values computed from 2D and 3D acquisitions were averaged separately for each study under basal and stenotic conditions. Two sample t-tests were performed to test whether (1) there were regional signal differences between basal and stenotic conditions under 2D and 3D SSFP acquisitions and (2) there were any differences in Regional SSFP BOLD contrast between 2D and 3D acquisitions under stenotic conditions. Statistical significance was set at  $p < 0.01$ .

**Results:** Figure 1 shows a representative set of end-diastolic 3D SSFP BOLD images (4 contiguous slices from apex to base) obtained from a dog under basal condition (upper row) and with moderate stenosis under adenosine stress (lower row). Note that under adenosine stress, the signal intensities in non-LCX supplied territories are higher than those in LCX supplied region while in baseline images, the signal intensities between non-LCX and LCX region are relatively isointense. Results from quantitative analysis are shown in Figure 2. No statistically significant regional signal differences were found between 2D and 3D acquisition under either basal or LCX stenosis with adenosine stress ( $p > 0.2$ ). However, statistically significant differences were found between baseline and LCX stenosis with adenosine stress for both 2D and 3D acquisitions.

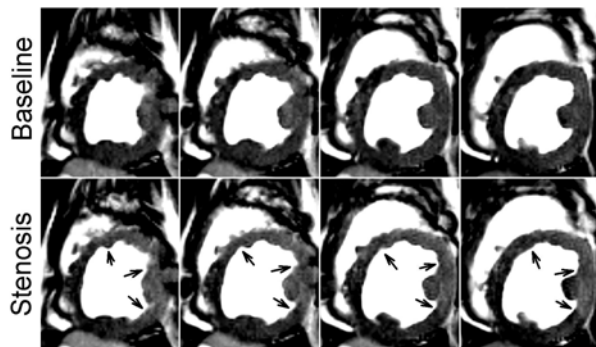


Figure 1. A representative set of end diastolic 3D SSFP BOLD images (4 contiguous slices from apex to base) obtained from a dog under baseline condition (upper row) and with moderate stenosis (lower row) with adenosine stress. Note that in the presence of LCX stenosis, signal intensity is different between non-LCX supplying territories (arrows) and LCX supplying territory.

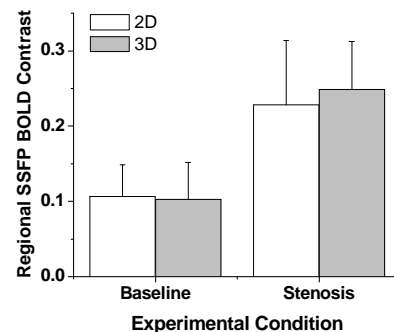


Figure 2. Regional 2D and 3D SSFP BOLD Contrast between LAD and LCX regions under baseline and stenosis (with adenosine) conditions. While there was no significant Contrast difference between 2D and 3D under either condition, a significant Contrast difference was observed between baseline and stenosis conditions ( $p < 0.01$ ) for both 2D and 3D scans.

**Discussion:** Although 2D SSFP BOLD imaging has shown promising results in the detection of myocardial oxygenation anomalies related to coronary artery stenosis, it has been suggested that SSFP signal modulation due to through-plane motion has the potential to impair the detection of myocardial oxygen changes. Results from this study showed that oxygen sensitivity between 2D and 3D acquisitions are not significantly different, demonstrating that through-plane motion may not significantly alter SSFP BOLD contrast. One of the limitations of the current implementation of 3D cine SSFP BOLD imaging is that, to preserve adequate image quality, the TR had to be limited to 4.7 ms. Given that 2D SSFP BOLD imaging at 1.5T can be reliably performed at a TR of 6.3 ms and that TR is directly related to oxygen sensitivity [3], improved artifact reduction methods permitting the use of higher TRs may be necessary to enhance 3D SSFP BOLD sensitivity. It is also anticipated that clinical translation of 3D cine SSFP BOLD imaging will require the utilization of faster data acquisition strategies and/or free-breathing approaches [4] to ensure reasonable patient comfort in the presence of pharmacological stress.

**References:** [1] Dharmakumar R et al. *Inves Radiol* 2007; [2] Green JD et al. *ISMRM* 2006; [3] Mangalathu JM et al. *MRM* 2008; [4] Larson AC et al. *MRM* 2004.