

## 4D bSSFP Myocardial BOLD Imaging with Flow Compensation: Early Results

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### Introduction

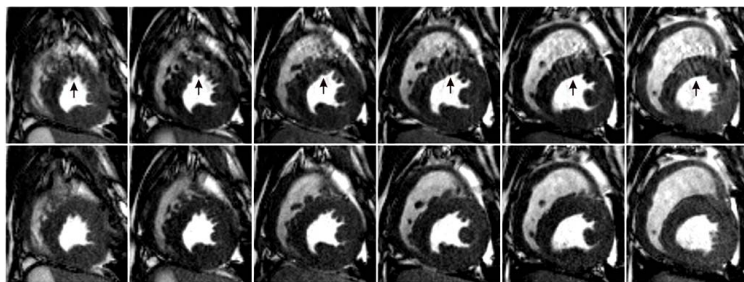
Flow and motion artifacts can degrade the image quality of 3D cine steady state free precession (bSSFP) Blood-Oxygen-Level-Dependent (BOLD) MRI [1-2]. A principle source of these artifacts originates from incomplete compensation of gradient moments that are above zeroth order leading to non-uniform phase changes over the repetition time (TR). These artifacts are particularly more pronounced in bSSFP-based BOLD MRI given the long TRs (typically > 6 ms) necessary to generate BOLD contrast. Thus methods that can reduce the effect of flow or motion are necessary to reliably identify the BOLD signal changes between ischemic and healthy myocardial territories. To minimize these artifacts, a first-order gradient moment compensated 3D SSFP sequence was developed and tested in a canine model with coronary artery stenosis.

### Methods

Flow compensation gradients were implemented in slice selection, phase encoding and readout directions to ensure that spins moving with a constant velocity do not accumulate incremental phase changes over each TR (Figure 1). Four healthy dogs were studied in a clinical 1.5T Espree system (Siemens Healthcare, Germany) to investigate the effect of first order flow/motion compensation on 3D long TR SSFP images over the whole left ventricle. Six to eight slices, centred on the mid-ventricle, were acquired in cine mode along the short axis with and without flow compensation: (A) TR/BW(ms/Hz/pixel) = 6.2/239 (without flow compensation); and (B) TR/BW = 6.2/930 (with flow compensation). Other scan parameters were: acquisition matrix=126 x 192, FOV=157.5mm x 240mm; slice thickness = 5mm; TE = 3.1ms; Flip angle = 70°, Temporal resolution = 19 ms, and parallel-imaging acceleration factor of 2 (in the phase-encoding direction). Myocardial BOLD studies with Approach B were performed in animals (n=2) with a controllable LCX stenosis [1,2]. Studies were performed under rest, and stress (constant adenosine infusion = 0.14 mg/kg/min) with no stenosis, and severe stenosis (reduction in LCX diameter > 80%).

### Results

Image artifacts from flow/motion were greatly reduced with first-order gradient moment compensation enabling the visualization of homogeneous myocardial signal intensities from the apex to base in healthy dogs. Figure 2 shows a set of non-flow compensated and flow-compensated images of six continuous slices from late systole. Figure 3 shows 3D flow-compensated systolic images (4 continuous short-axis slices) acquired in a dog under baseline, adenosine stress, and adenosine stress with severe stenosis of the LCX. Note the discriminating signal loss in the inferior wall (LCX supplying territory) in the presence of LCX stenosis, and the relative homogeneity of the myocardium at baseline and stress without stenosis.



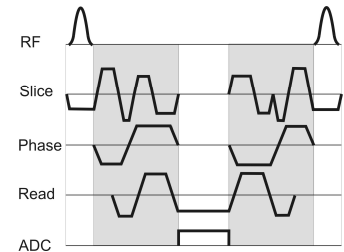
**Fig. 2.** Short-axis systolic images acquired in a healthy dog using 3D cine BOLD SSFP sequences without (top) and with (bottom) flow compensation from the apex (left) to the base of the heart (right). Note the relative homogeneity of the myocardium in the flow compensated images and the presence of image artifacts reducing the signal homogeneity of the myocardium in non-flow compensated images.

### Conclusions

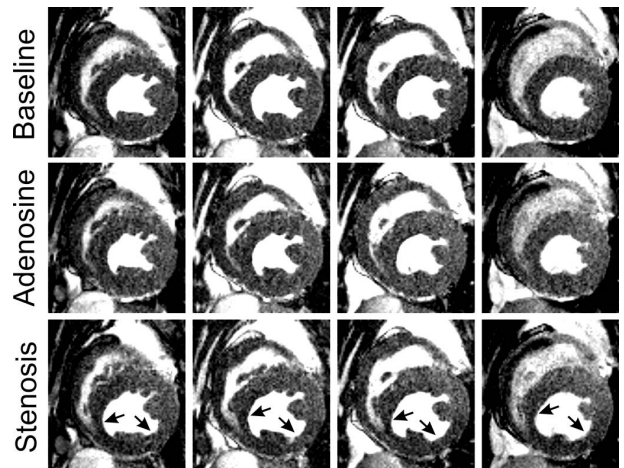
First-order motion compensation strategies employed here provide substantial reduction in flow/motion related artifacts. Results also confirmed that this method was able to delineate the BOLD signal changes throughout the cardiac cycle with 3D coverage in animals with coronary artery stenosis. Additional studies are necessary to evaluate the robustness of the technique. Clinical translation of this method is currently limited by the long breath-holding time (approximately 30-40 seconds). Free-breathing approaches may be necessary prior to its evaluation in patients suspected of coronary artery disease.

### References

[1] Zhou X *et al* ISMRM 2009; [2] Dharmakumar R *et al* Invest Radiol 2007.



**Fig. 1.** Timing diagram for the first-order moment compensated 3D SSFP sequence. Note that the motion compensation is performed in all 3 directions.



**Fig. 3.** Flow compensated 3D Cine SSFP images (only late systolic phase is shown) of 4 slices centred on the mid ventricle from a dog under baseline, adenosine infusion, and 80-90% LCX stenosis with adenosine infusion. Note that in images acquired under severe stenosis, the areas subtended by the arrows (LCX supplying territory), are significantly more hypointense relative to other territories.