Ungated Cardiac-Phase-Resolved First-Pass MRI for Concurrent Imaging of Myocardial Function and Perfusion at Peak Stress

Behzad Sharif[1], Reza Arsanjani[1], Rohan Dharmakumar[1], Noel Bairey Merz[1], Daniel S Berman[1], and Debiao Li[1]
[1]*Biomedical Imaging Research Institute, Dept. of Biomedical Sciences, Cedars-Sinai Medical Center, Los Angeles, California, United States*

INTRODUCTION and PURPOSE: Among the spectrum of ischemic heart disease patients, those suffering from high grade (85%-100%) stenosis are at a significantly elevated risk for adverse events [1]. In the field of nuclear cardiology, it is known that wall motion abnormalities under vasodilator (adenosine/regadenoson) stress is indicative of the so-called "coronary steal" phenomenon [2] caused by such high-grade stenoses. Furthermore, recent studies in the nuclear imaging community have shown that combined quantification of left ventricular wall thickening and rest-stress myocardial perfusion provides incremental gains in diagnostic accuracy of coronary artery disease (CAD) [1]. Consequently, simultaneous imaging of myocardial function and perfusion at peak vasodilator stress can equip cardiac MRI with the capability of assessing high grade stenosis on the basis of wall motion abnormalities observed during the stress scan. We present an innovative ungated first-pass perfusion (FPP) imaging method that does not require ECG gating, and is capable of reconstructing the myocardial perfusion imaging at any desired cardiac phase, i.e., a "*cardiac phase resolved*" FPP imaging approach.

METHODS: FPP imaging without magnetization preparation using a "magnetization-driven" acquisition was described by Judd et al. almost 2 decades ago [3] and has seen recent interest [4-7]. By adopting a similar approach as the "real time" FPP method in [6-7], our proposed pulse sequence performs T1-weighted radial (golden angle) sampling of 3 slices continuously and without ECG synchronization, as described in Fig. 1(A). The T1 contrast is generated by the approximate steady state of the RF-spoiled GRE sequence. Patients with prior abnormal nuclear myocardial perfusion scans were recruited for a stress/rest cardiac MRI study on a 3T clinical scanner (Siemens Verio) using the proposed ungated pulse sequence (40-second scan, approx. 6000 projections acquired, TR = 2.5 ms, flip angle =21°, 3 slices imaged at 1.7x1.7 mm^2 in-plane resolution). The reconstruction method used automatic self-gating as described in Fig. 1(B,C) and optimally apodized (as in [8]) compressed sensing for accelerated reconstruction of the cardiac-phase-resolved FPP image series.

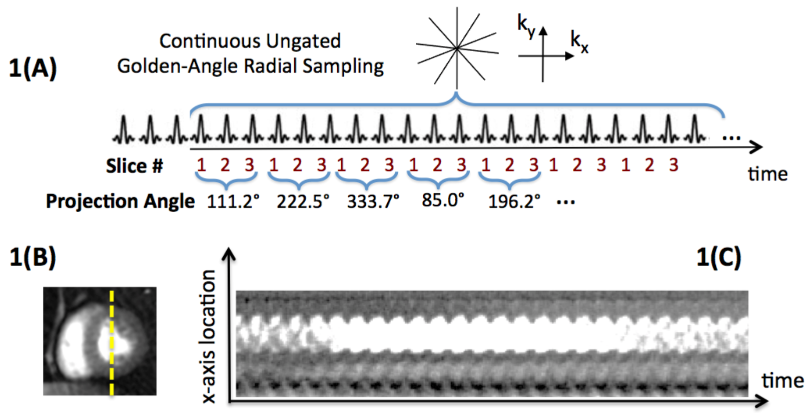

Fig. 1. (A) Schematic for the proposed "magnetization driven" T1-weighted pulse sequence with golden-angle radial sampling; 3 slices are acquired without ECG gating in an interleaved continuous fashion. **(B,C)** An example "x-t" profile (temporal evolution of a 1D cut shown in panel B) for the first-pass scan in shown in panel (C). This profile is used for retrospective self-gating of the continuously acquired data enabling reconstruction of the myocardial perfusion images at any desired cardiac phase thereby capturing the myocardial function and wall motion during the first-pass scan, specifically at peak stress.

RESULTS: Results for a representative patient study are shown in Fig. 2. The left panel shows the stress/rest myocardial perfusion images for 3 short-axis slices (peak myocardial enhancement phase) demonstrating stress-induced subendocardial defects (yellow arrows). As shown in the right panel labeled "Cine Recon" the end-systolic volume (ESV) for this patient is higher under stress compared to rest, which is a pathological finding. In fact, for normal subjects, the heart contracts more under stress thereby resulting in a lower ESV at peak stress; however, the opposite is seen for this patient in Fig. 2. This finding was also seen on the subject's prior nuclear myocardial perfusion study (which also measures cardiac function under stress and rest). Further, as show in the bottom-right panel this subject suffers from subtotal stenosis (proximal antegrade branch) based on invasive coronary angiography, which is consistent with the observed stress-induced wall motion abnormality.

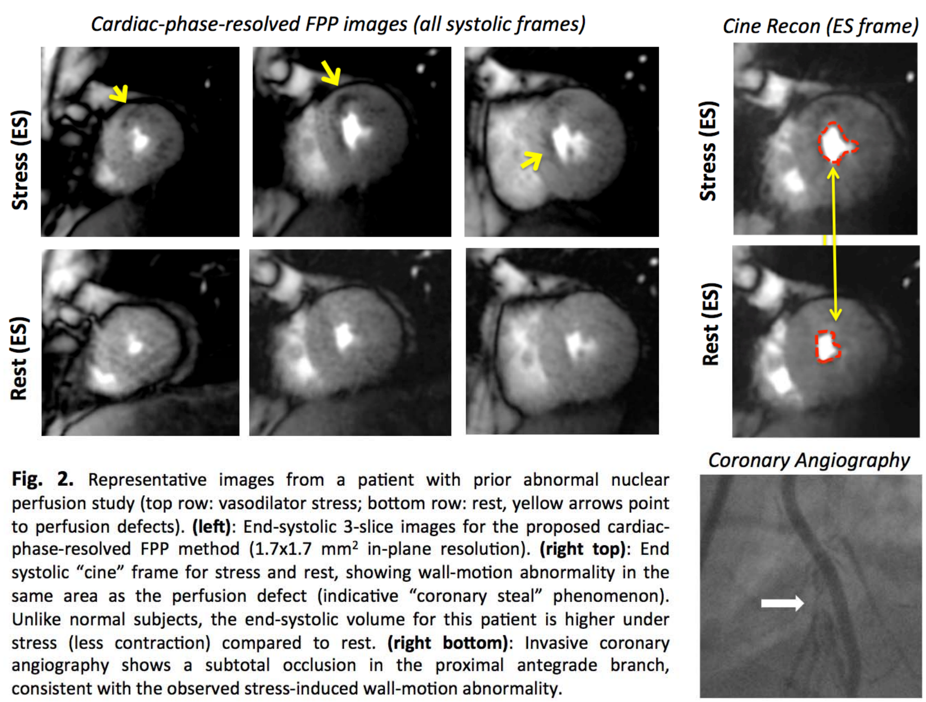

Fig. 2. Representative images from a patient with prior abnormal nuclear perfusion study (top row: vasodilator stress; bottom row: rest, yellow arrows point to perfusion defects). **(left)**: End-systolic 3-slice images for the proposed cardiac-phase-resolved FPP method (1.7x1.7 mm^2 in-plane resolution). **(right top)**: End systolic "cine" frame for stress and rest, showing wall-motion abnormality in the same area as the perfusion defect (indicative "coronary steal" phenomenon). Unlike normal subjects, the end-systolic volume for this patient is higher under stress (less contraction) compared to rest. **(right bottom)**: Invasive coronary angiography shows a subtotal occlusion in the proximal antegrade branch, consistent with the observed stress-induced wall-motion abnormality.

DISCUSSION: We presented an innovative ungated first-pass cardiac MRI method capable of cardiac-phase-resolved perfusion imaging. This method enables assessment of myocardial function and perfusion at peak stress, which can identify high-grade stenosis thereby identifying high-risk CAD patients. Future clinical studies are needed to systematically assess the diagnostic benefits of the developed method for the general CAD population.

References [1] Emmet et al., JACC 2002(39), p. 991-8. [2] Iskandarian et al., J Nuc Cardiol 1994(1), pp. 94-111. [3] R. Judd et al. MRM 1995; 34:276-82. [4] E. DiBella et al., MRM 2012;67. [5] S. Giri and O. Simonetti: MRM 2013. [6] B. Sharif and D. Li et al., ISMRM 2013, p. 1401. [7] B. Sharif and D. Li et al., JCMR 2013, 15(Suppl 1):O1. [8] B. Sharif and D. Li et al., MRM, Epub ahead of print Sep 2013. doi: 10.1002/mrm.24913