Improved Visualization of Myocardial Perfusion Defects Using Ungated Continuously-sampled Radial First-Pass MRI with Comparison to ECG-gated Imaging

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INTRODUCTION: The effects of myocardial ischemia are first realized in the subendocardium and progress transmurally. Hence, detection of the *transmural extent* of myocardial perfusion (MP) defects has important diagnostic/prognostic implications in patients with suspected coronary artery disease (CAD) [1]. Systolic first-pass perfusion (FPP) imaging using ECG-gated methods has been shown to provide improved visualization of subendocardial defects [1]. However, the need for accurate ECG gating in stress MRI studies can be challenging in the presence of arrhythmias or heart-rate variations, thereby reducing robustness and reliability of FPP imaging.

PURPOSE: To develop a *non-ECG-gated* radial FPP technique capable of imaging all slices at *the same systolic phase*, and compare its ability in visualizing the transmural extent of perfusion defects to the conventional gated FPP method in stress/rest studies.

METHODS: A non-ECG-gated continuous acquisition scheme was developed using a steady-state FLASH sequence to achieve multi-slice T1-weighted imaging without saturation recovery (SR) preparation [2-5]. The sampling scheme (Fig. 1a) used radial readouts acquired *continuously* in a slice-interleaved order (flip angle: 30°, TE: 1.4 ms, echo spacing: 2.7 ms, prescribed resolution: 1.4x1.4x10 mm^3). Retrospective systolic self-gating was performed automatically based on a low-resolution real-time reconstruction (25 frames/sec). The self-gated data was then used to perform high-resolution reconstruction of *all slices in the same systolic phase* using a compressed sensing approach (12-fold spatio-temporal acceleration) described by the following optimization functional and schematically in Fig. 1b:

$$\hat{x}_t = \underset{x_t}{\operatorname{argmin}} \left\{ \sum_{c=1}^{N_c} \left\| y_{c;t} - A_t(S_c x_t) \right\|_2^2 + \lambda \, \mathrm{TV}(x_t - r_t) + \eta \, \| x_t - r_t \|_1 \right\}$$

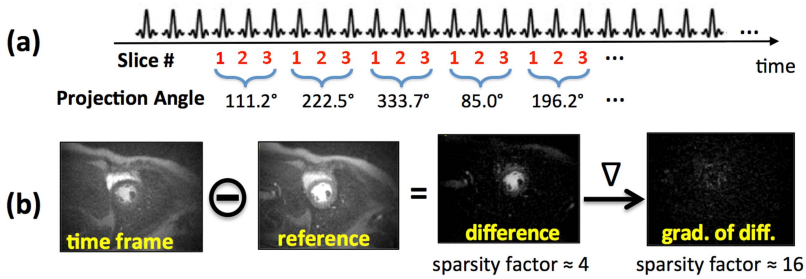

Fig 1. (a): Data acquisition scheme for the proposed steady-state multi-slice *continuous FPP method* using a non-ECG-gated FLASH sequence with golden-angle continuous radial sampling. 3 short-axis slices are acquired continuously with the projections acquired in a slice-interleaved order. No ECG signal is recorded for the proposed method. **(b):** Description of the data-driven sparsity transform. A reference-based difference operator is applied to the FPP time frame (denoted by x_t) followed by the gradient operator resulting in a high sparsity factor. The reference image (denoted by r_t) is formed using a sliding-window and non-Cartesian SENSE reconstruction.

where x_t is the unknown image for the FPP time-frame that is being reconstructed, r_t is its corresponding reference image (sliding-window SENSE reconstruction), A_t is the golden-ratio radial sampling operator for the current time-frame; $y_{c;t}$ and S_c are the k-space data and the coil sensitivity for *c*-th channel, and (λ, η) are the parameters enabling trade-off of data fidelity versus sparsity constraints. The operators $\|.\|_2, \|.\|_1$,TV denote 2-norm, 1-norm, and total variation, respectively.

In total 30 stress/rest FPP studies were conducted at 3T in healthy subjects (n=5) and patients (n=10) with suspected CAD (identified using prior nuclear exams) using the proposed method (1st visit), and the conventional ECG-gated SR-prepared method (2nd visit).

RESULTS: The non-ECG-gated FPP studies in healthy subjects demonstrated normal perfusion, no dark-rim artifacts, and similar contrast-to-noise ratio (CNR) in the septal myocardium (contrast measured as the difference between the pre-contrast frame relative to the peak enhancement frame) compared with the conventional scheme (8.6±0.6 vs. 8.0±0.7, respectively). A representative stress/rest CAD patient study is shown in Fig. 2. Among all patients who had an abnormal FPP study (n=8), the detected stress MP defects matched between the two methods (after ruling out artifacts based on rest FPP and LGE scans and patient history; 2 expert readers). Of all the observed defects on stress MP images, 26% of the conventionally-acquired MP images were at or near end-diastole, making it infeasible to visualize their transmural extent. In contrast, the transmural extent for all perfusion defects corresponding to the proposed method was easily visualized (example shown in Fig. 2).

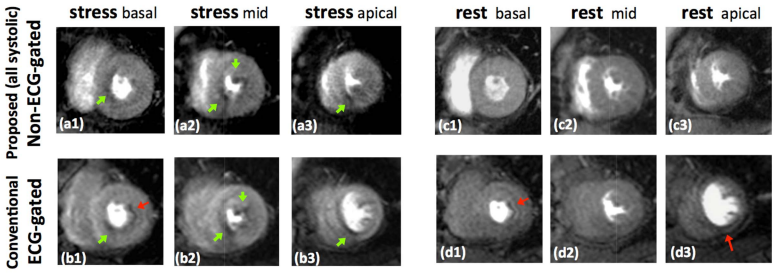

Fig 2. Representative adenosine stress/rest patient study. **(a,b): stress** myocardial perfusion study using the proposed non-ECG-gated method (1st visit) and the conventional ECG-gated method (2nd visit); **(c,d): rest** myocardial perfusion studies corresponding to each of the two methods for the same patient. Red arrows point to subendocardial dark-rim artifacts (LGE scan was negative). The stress-induced MP defects (green arrows) were closely matched between the two methods. However, the apical slice for the conventional scan was imaged at diastole (reducing the reliability of detecting the transmural extent), while the proposed non-ECG-gated method was capable of imaging all slices at the same systolic phase.

DISCUSSION: The healthy volunteer studies showed that the myocardial CNR using the continuously sampled steady-state method is not compromised compared to SR-prepared imaging. Our preliminary results in CAD patients demonstrated the feasibility of detecting the transmural extent of subendocardial perfusion defects in all imaged slices, which has significant clinical value in terms of determining the severity of ischemic heart disease [1]. In contrast, the conventional ECG-gated FPP method does not provide the freedom to image all slices at systole. Moreover, the developed ungated method has the advantage of simplicity (no need for accurate ECG) and thereby potentially improved reliability compared to 2D or 3D gated methods. More studies with direct comparison to a reference gold-standard (invasive angiography) are needed to rigorously evaluate the potential diagnostic benefits of the proposed "all systolic" non-ECG-gated FPP approach in patients with suspected CAD.

References: [1] M. Motwani and S. Plein et al., Radiology 2012;262:816-23. [2] E. DiBella et al., MRM 2011;67:609-13. [3] B. Sharif and D. Li et al., MRM, Early View: Jan 2014. [4] B. Sharif and D. Li et al., ISMRM 2014, p. 879. [5] H. Wang and E. DiBella et al., ISMRM 2014, p. 3934.