Steady-state Real-time Cine Imaging of Stress/Rest Myocardial Perfusion for Rapid Detection of High-grade Coronary Stenosis

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INTRODUCTION: Among the spectrum of patients with coronary artery disease (CAD), those suffering from high-grade stenosis are at a significantly elevated risk for adverse events [1]. Such high-grade disease may result in the so-called "coronary steal" phenomenon under vasodilator stress [2] thereby inducing wall motion (WM) abnormalities (WMAs) in the affected territories, referred to as "transient ischemic dilation" [3]. We developed a "real time" cine first-pass perfusion (FPP) cardiac MRI method for concurrent imaging of myocardial perfusion and function. We hypothesized that this method is capable of simultaneously capturing stress-induced perfusion defects and WMAs in a single ungated scan, thereby enabling rapid detection of hemodynamically significant severe coronary stenoses.

PURPOSE: To develop a cardiac phase-resolved "real-time cine" FPP technique enabling concurrent MRI of myocardial perfusion and function, and test the hypothesis that stress-induced WMAs in perfusion defect territories indicate the presence of high-grade stenosis.

METHODS: Canines (n=10) with surgically implemented reversible coronary stenosis below the first diagonal along the left anterior descending (LAD) artery (≅90% stenosis) were studied at 3T. Real-time adenosine stress/rest cine FPP data was acquired using an *ungated continuously-sampled* sequence without saturation recovery preparation [4,5]. The T1-weighted acquisition scheme, shown in Fig. 1a, used a steady-state FLASH sequence with 3-5 slice coverage and no time-gap in between consecutive slice-interleaved radial readouts, acquiring 5,000 projections per slice during the 40-second real-time FPP scan (flip: 30°, echo spacing: 2.7 ms, in-plane resolution: 1.4x1.4 mm^2). Retrospective cardiac self-gating was performed following a high temporal-resolution real-time reconstruction of the mid slice at low spatial resolution (25 frames/s). Figure 1b shows an example for the this self-gating algorithm (described in the caption), which automatically assigns end-systolic/diastolic time stamps to the radial k-space data. The self-gating information was then used to perform a *cardiac phase-resolved reconstruction of the FPP data for all slices* at high spatial resolution employing a reference-constrained compressed sensing approach [6] with 12-fold spatio-temporal acceleration (anatomical reference images were generated using non-Cartesian SENSE with a 7-heartbeat sliding-window). The WM for the cine FPP images was scored based on a standard 1-4 scale (2 expert readers).

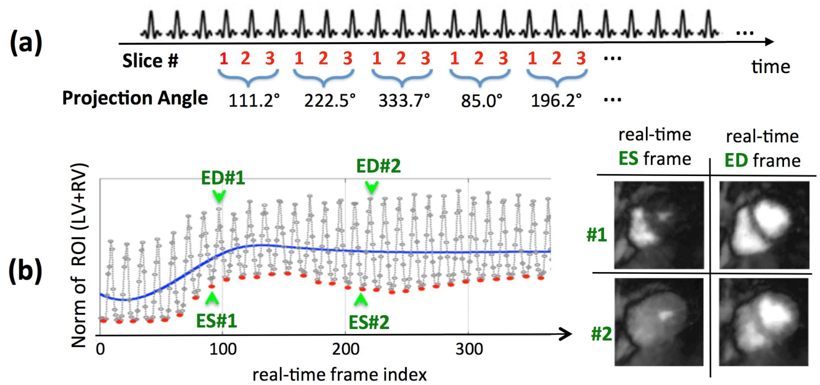

Fig 1. **(a):** Schematic description of the steady-state (RF-spoiled gradient echo) FPP data acquisition scheme for the developed *real-time cine FPP method* using a non-ECG-gated FLASH sequence with golden-angle continuous radial sampling. Multiple short-axis slices are acquired continuously with the projections acquired in a slice-interleaved order. **(b):** Example result (stress FPP scan) for the automatic self-gating algorithm. First, a real-time reconstruction of the mid slice is performed at 25 frames/sec (sliding-window non-Cartesian SENSE from only 8 projections followed by temporal TV filtering) and the resulting images (*shown on the right-hand side*) are cropped to the detected ROI consisting of both the left and right ventricles. Next, a 1D plot is generated by calculating the 2-norm of the cropped real-time images and a 3-piece cubic B-spline curve (blue curve) is fitted to this 1D plot (least-squares fit). Finally, the local minima and maxima in each of the detected intervals (intersection points with the blue curve) are identified as end-systolic (ES) and end-diastolic (ED) "time stamps," respectively (red dots indicate ES stamps).

RESULTS: Real-time stress FPP scans in stenotic dogs (Fig. 2) showed worsening of WM in the detected perfusion defect territories compared to resting function (slice-averaged stress WM score for defect region: 2.8 vs. 1.65 for rest; $p < 0.05$). This is consistent with the transient ischemic dilation (coronary steal) phenomenon under vasodilator stress [2,3]. The close agreement of WM patterns in the real-time cine FPP images vs. standard cine images (mid slice in (a) and (b) vs. (c) in Fig. 2) indicates the high temporal resolution of the real-time method, enabling it to accurately caption the WMAs.

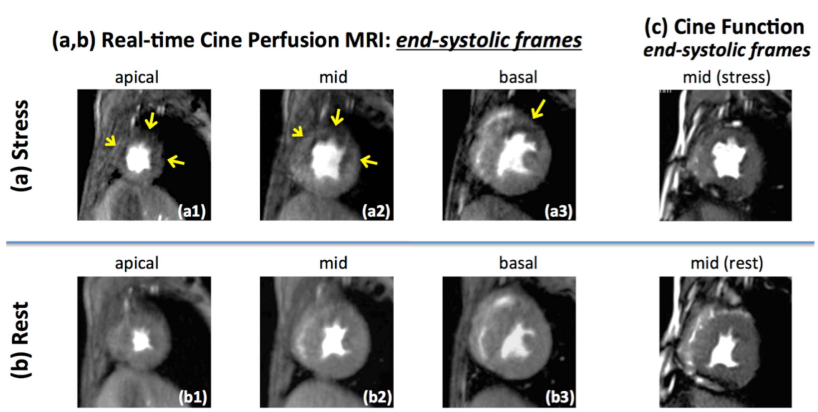

Fig 2. Representative images from the ischemic canine stress/rest studies (n=10) with high-grade LAD stenosis. **(a,b):** End-systolic adenosine stress and rest first-pass perfusion images (peak enhancement phase) using the developed real-time cine FPP method. **(c):** Standard gated SSFP cine end-systolic images (mid slice), showing a similar stress-versus-rest WMA pattern as in (a,b). This confirms that the real-time cine FPP technique has accurately captured the WM by achieving sufficient temporal resolution.

DISCUSSION: CAD patients suffering from high-grade stenosis are at a much higher risk for adverse events [1,2]. We presented a multi-slice cine FPP method capable of simultaneous detection of stress-induced perfusion defects and WMAs in a single 40-second ungated scan using continuously sampled radial acquisition. Our initial results demonstrate that worsening of WM (compared to rest) in the perfusion defect territories seen in the real-time stress cine FPP scan may be a marker of severe CAD. Future work will focus on evaluation of the developed method in stress/rest FPP studies of patients with suspected CAD.

References: [**1**] Emmet et al. JACC 2002;39:991-8. [**2**] Patterson and Kirk, Circulation 1983;67:1009-15. [**3**] Abidov et al. JACC 2003;42:1818-25. [**4**] DiBella et al. MRM 2012;67:609-13. [**5**] Sharif and Li et al. MRM, Epub Jan 2014. [**6**] Kamalabadi and Sharif, Proc IEEE ICIP 2005;2:205-8.