MOTION-INDUCED DARK-RIM ARTIFACT IN FIRST-PASS MYOCARDIAL PERFUSION MR: A CONTROLLED CANINE STUDY

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INTRODUCTION First-pass myocardial perfusion (MP) MR imaging is a promising technique for non-invasive evaluation of ischemic heart disease [1,2]. A major limiting factor for specificity and sensitivity of current MP MR methods is the so-called subendocardial dark-rim artifact (DRA) [2-4], which may mimic subendocardial perfusion deficits or impede the detection of small deficit regions. It is known that DRAs in conventional Cartesian imaging protocols are caused by a combination of factors including: (i) Gibbs ringing caused by low spatial resolutions along the phase-encode (PE) direction [2-5]; and (ii) cardiac motion effects, first described by Storey et al. in [6]. In this work, we aimed at improving the analysis of Storey et al. [6] by considering the combined effect of cardiac motion and limited spatial resolution (Gibbs ringing) on both the spatial extent and temporal persistence of the DRA. We performed first-pass MP MR on healthy dogs at moderate to high heart-rates (HRs) to evaluate the effect of motion on the DRA. In addition, we present initial results for an alternative highly-accelerated radial imaging scheme that can potentially eliminate the DRA due to motion.

THEORY The effect of cardiac motion during the readout of multiple PEs in a MP MR scan can be described as a convolution in the image domain with an oscillating point-spread function, say $\boldsymbol{\psi_M}$, as described in [6]. Denote the underlying (true) MP frame by $\boldsymbol{x_t}$, which contains sharp edges as is the case for the wash-in phase of MP images. The combined effect of Gibbs-ringing (caused by limited spatial resolution along PE) and cardiac motion can be described as: $\hat{\boldsymbol{x}} = |\boldsymbol{x_t} * \boldsymbol{\psi_M} * \boldsymbol{\psi_G}|$, where $\hat{\boldsymbol{x}}$ denotes the imaged (reconstructed) frame. Figure 1 demonstrates this by showing simulation results for a contracting left ventricular (LV) numerical phantom. Panel (a) shows a high-resolution representation of the phantom (256x256 image matrix) with no motion (almost no DRA is observed). Panel (b) shows the reconstruction of the moving phantom with 256 PEs (minimal DRA is observed with transmural extent of <10%). Finally, Panel (c) shows the reconstruction with 108 PEs and the same extent of motion as in (b), which results in significant DRA (>25% transmural extent).

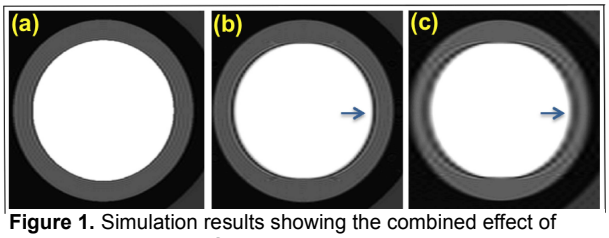

Figure 1. Simulation results showing the combined effect of motion and Gibbs ringing. Arrows point to DRAs.

METHODS Healthy dogs (N=3; weight 20-25 kg) were scanned on a clinical 3T scanner (Siemens Magnetom Verio, Erlangen, Germany) with approval from the Institutional Animal Care and Use Committee. The animals were ventilated and anesthesia was administered (2.5% isoflurane and 100% oxygen). First-pass perfusion MR imaging with a Gadolinium-based contrast agent (dose: 0.04 mmol/kg) was conducted during a breath-hold (by turning off the respirator for 30-40 s). The first MP scan was performed at resting HR (79-93 bpm) using the product SR-prepared FLASH sequence with parallel imaging and was followed by a 15 minute wait to allow for contrast wash-out (imaging parameters: TR/TE/TI = 2.9 ms/1.6 ms/100 ms, flip angle = 12 degrees, FOV = 270mm x160 mm, resolution=1.7x2.6x6.0 mm, TGRAPPA factor = 2, acquisition window = 90 msec). Next, Epinephrine (0.5-1.0 mg bolus) was administered to increase the HR to 140-150 bpm. The second first-pass MP scan was started 2-4 minute afterwards. For the 3rd dog, the last two steps were repeated for a second time using an accelerated multi-shot interleaved SR-prepared radial scan (sequence parameters similar to [7] with acquisition window of 35 msec) with modified HYPR-based reconstruction using a compressed-sensing approach.

RESULT Figure 2 shows 6 consecutive frames from the rest (HR range: 79-84 bpm, avg. for frames shown: 82) and high-HR (HR range: 137-165 bpm, avg. for frames shown:150) MP scans for the 2nd dog. Comparing the two rows (differences are highlighted by arrows), the DRAs for the high-HR scan are spatially more prominent, i.e., have a wider transmural extent; also, they are more temporally persistent. This observation matches with the theory described above. Figure 3 shows one MP frame at the early myocardial enhancement phase for the 3rd dog. Panel (a) and (b) correspond to the resting-HR scan (range: 82-93 bpm, frame shown: 89), and high-HR scan (range: 140-148 bpm, frame shown: 146), respectively. Finally, Panel (c) shows the corresponding frame for the high-resolution multi-shot radial scan (HR range: 133-158 bpm, frame shown: 142). It can be concluded that the DRAs in (a) are mainly induced by Gibbs ringing whereas those in (b) are more prominent due to the additional effect of motion (follows the above-mentioned theory). The result in (c) shows some blurring due to the multi-shot nature of the acquisition scheme and the significant arrhythmia present during the scan. However, no DRAs are observed due to the narrower acquisition window and intrinsic robustness of radial acquisition to Gibbs ringing [8].

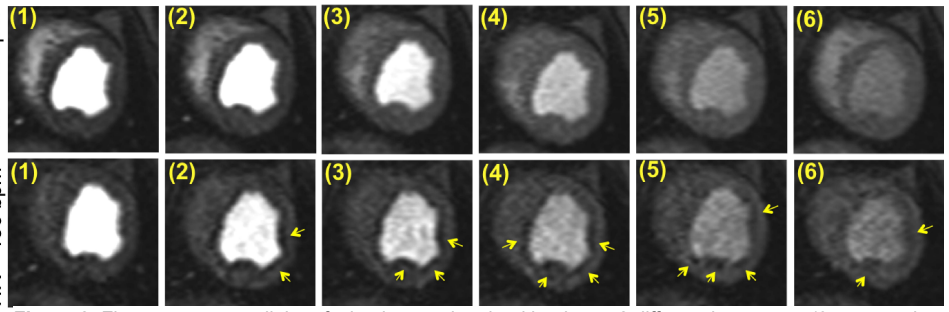

Figure 2. First-pass myocardial perfusion images in a healthy dog at 2 different heart rates (6 consecutive frames). Arrows point to DRAs that are only observed in the very high HR (160bpm) images.

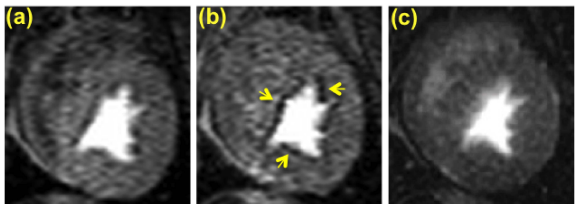

Figure 3. MP images (at early myocardial enhancement phase) for 3rd dog at (a) resting HR (89 bpm); (b) high HR (146 bpm); (c) accelerated radial scan at high HR (142 bpm).

DISCUSSION Building on the analysis of Storey et al. [6], we showed that the extent of the DRA not only depends on the relative motion speed but also on the spatial resolution (example show in Fig. 1). That is, Gibbs ringing along PE affects the extent of the DRA significantly. The presented in-vivo results demonstrated the effect of high HRs on the spatial extent and temporal persistence of the motion-induced DRAs. In addition, we provided a potential solution by presenting results for an alternative highly-accelerated projection-based scheme.

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