Reducing Dark-Rim Artifacts in Free-Breathing First-Pass Perfusion Cardiac MRI With Cartesian Sampling and Instantaneous Image Reconstruction

Zhengwei Zhou[1,2], Xiaoming Bi[3], Hsin-Jung Yang[1,2], Rohan Dharmakumar[1], Reza Arsanjani[1,4], C Noel Bairey Merz[4], Daniel Berman[1,4], Debiao Li[1,2], and Behzad Sharif[1]

[1]Biomedical Imaging Research Institute, Cedars-Sinai Medical Center, Los Angeles, CA, United States, [2]Department of Bioengineering, University of California, Los Angeles, Los Angeles, CA, United States, [3]MR R&D, Siemens Healthcare, Los Angeles, CA, United States, [4]Cedars-Sinai Heart Institute, Los Angeles, CA, United States

Background: Presence of dark-rim artifacts (DRAs) continues to be a major issue that limits the diagnostic performance of first-pass perfusion (FPP) MRI for assessment of myocardial ischemia [1,2]. Non-Cartesian approaches such as radial or spiral acquisition have been proposed to minimize DRAs [3-5]. However, these approaches typically require a time-consuming offline image reconstruction procedure, which limits their clinical accessibility. We propose a free-breathing DRA-reduced FPP scheme with Cartesian k-space sampling and instantaneous "online" image reconstruction.

Methods: Healthy subjects (n=10) were studied on a 3T clinical scanner (Magnetom Verio, Siemens) using the standard 12-channel cardiac coil. Two free-breathing FPP scans (3 slice coverage) were performed at rest, first using the proposed method followed by a conventional method (15 minute gap). Apodization of k-space data is known to reduce Gibbs ringing effects, a major underlying cause of the DRA [1,4,5]. It also enhances signal-to-noise (SNR) but comes at the cost of lower resolution. In the proposed method, an unusually high parallel imaging factor (R=4 fold GRAPPA) with Cartesian sampling is used to acquire a high-resolution FPP scan (in-plane resolution: 1.7 x 1.7 mm^2). Following parallel imaging reconstruction, an optimized Gaussian apodizer is applied, which both reduces Gibbs ringing and improves SNR. Based on numerical analysis of the underlying point spread function, the apodization level (effective level of resolution reduction) was adjusted so that the apodized images had the same resolution as the conventional FPP scan (in-plane resolution: 2.7 x 2.2 mm^2). Apodization was implemented as an additional post-filtering step within the Siemens Image Calculation Environment (ICE) and it was integrated to the online image reconstruction routine of the scanner. Images were scored by two expert readers blinded to the protocol (consensus scoring; artifact scale: 0 = No DRA, 4 = Severe DRA; image quality scale: 1 = poor, 5 = excellent). Myocardial SNR was measured in the septum separately and averaged over all 3 slices. To test the effectiveness of the method in identifying subendocardial perfusion defects, dogs with myocardial infarction (n=2) and one control dog were studied under a similar setting. Late gadolinium enhancement (LGE) images were used as the reference for detection of expected defects.

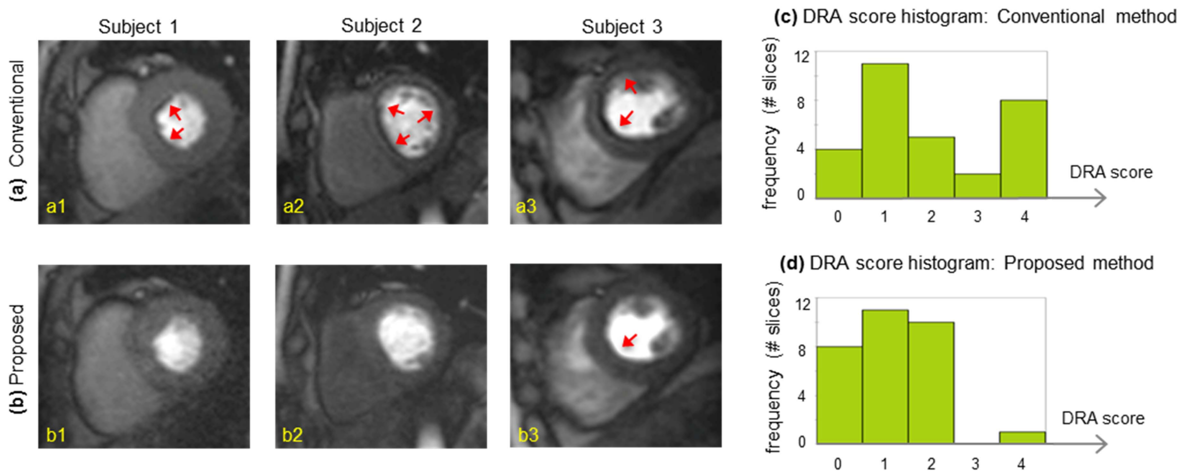

Figure 1.(a,b): Representative rest FPP images of three healthy subjects. Images in the top panel **(a1-a3)** correspond to the latest vendor-provided conventional FPP method and the bottom row (b1-b3) corresponds to the proposed perfusion CMR technique. As can be seen, the number of segments affected by DRAs and their severity is reduced in the bottom row (proposed method) compared to the top row (conventional method). **(c,d):** Histogram of DRA scores for the proposed and conventional methods.

Results: Fig. 1(a,b) shows representative images and the histogram of DRA scores are presented in Fig. 1(c,d). All images were reconstructed online (<10 seconds following the completion of the scan). The mean DRA score for the proposed method is significantly lower than the conventional method (1.2 versus 2.0, $p<0.01$). Importantly, the histogram of artifact scores in Fig. 1(c,d) shows a significant reduction in the number of slices with severe DRAs (scores 3 and 4) for the proposed method compared to the conventional method (10 slices versus only 1 slice). The image quality scores of proposed method was shown to be slightly lower (4.1 for the proposed method and 4.3 for conventional), but the difference was statistically insignificant ($p=0.2$). This was consistent with the quantitative myocardial SNR measurements result (13.0 for proposed method and 14.1 for conventional; $p = 0.3$). Fig. 2 shows example results from the canine studies, demonstrating that FPP images acquired with proposed method can detect small subendocardial defects corresponding to infarct territories seen on the LGE images (a defect width of 3 mm is highlighted). The results demonstrate the reduction of subendocardial DRAs using apodization (applied to a high-resolution scan) does not lead to elimination or masking of subendocardial defects in the reconstructed images.

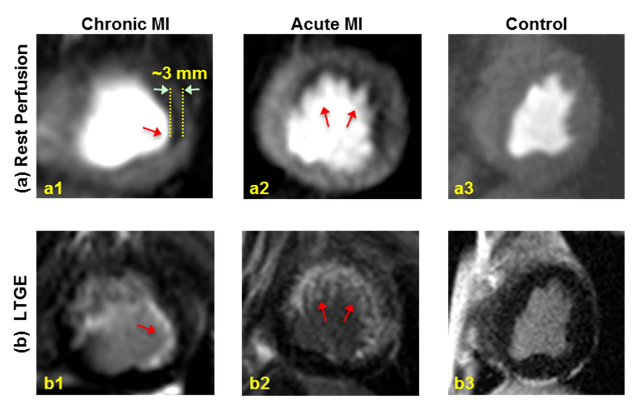

Figure 2. **(a)** Rest FPP images (peak myocardial enhancement); and **(b)** corresponding LGE images in canine models of myocardial infarction (MI). Images in the first column correspond to a chronic MI dog study that shows a small subendocardial defect (≈3 mm width) in the lateral wall (matches the LGE image). This subendocardial defect is clearly visualized demonstrating the ability of the proposed method to resolve small defects.

Conclusions: We have developed an optimized Cartesian sampling and apodization scheme for free-breathing first-pass perfusion cardiac MRI. Compared to the conventional FPP imaging method, the severity and prevalence of subendocardial DRAs were significantly reduced. A key feature of the proposed method is that it uses the widely available parallel imaging reconstruction software to achieve near-instant reconstruction on the scanner, potentially enhancing its accessibility in clinical studies compared to alterative non-Cartesian schemes.

References: [1] DiBella EVR et al., MRM 2005;54:1295-99. [2] Gerber BL et al., JCMR 2008;10:18. [3] Salerno M et al., MRM 2011;65:1602-10. [4] Salerno M et al., MRM 2013;70:1369-79. [5] Sharif B et al., MRM 2014;72:124-36.