# MINIMIZING DARK-RIM ARTIFACTS IN FIRST-PASS MYOCARDIAL PERFUSION MR BY ELIMINATING GIBBS RINGING USING PROJECTION IMAGING

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**INTRODUCTION** First-pass perfusion (FPP) cardiac MRI is clinically used to assess myocardial ischemia and has been shown to provide relatively high accuracy in clinical trials. However, a major limitation for FPP is the presence of the so-called dark rim artifacts (DRAs), which may confound interpretation and diagnosis of subendocardial perfusion defects [1]. A major cause of DRAs is known to be Gibbs ringing along the subendocardial border, a fundametinal property of Fourier (k-space) sampling [1-4]. **The purpose of this work is** to demonstrate that projection imaging significantly reduces the prevalence and spatial extent of subendocardial DRAs in FPP myocardial imaging, compared to conventional Cartesian techniques.

**THEORY** Consider the schematic in Fig. 1(a)., which shows two k-space sampling patterns: one is Cartesian and the other is radial but both have the same number of readouts (phase-encodes in case of Cartesian) and the same readout resolution. The corresponding point spread functions (PSFs) are shown in Figs 1(b)-(c) (absolute value of PSFs for 80 readouts). Insufficient coverage along phase-encode direction with Cartesian sampling results in significant ringing in image domain (Fig. 1b). In contrast, angular undersampling results in streaks outside of a local region for radial images [5,6]. The reduced ringing in the PSF enables radial imaging to exhibits minimal Gibbs effects (hence eliminating a major cause of DRAs).

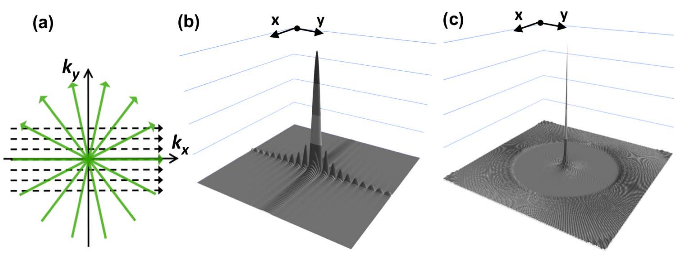
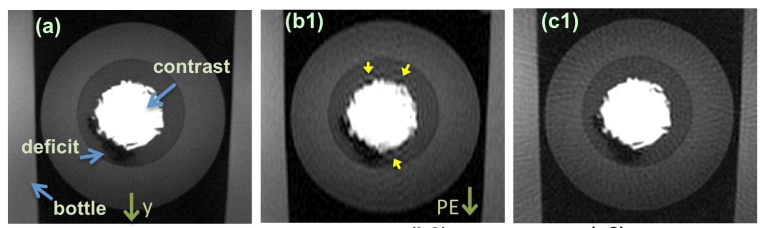



**Fig 1.** **(a)** Schematic showing Cartesian and radial k-space sampling patterns with the same number of readouts and readout resolution. **(b, c):** Absolute value of the Cartesian and radial PSFs with 80 readouts and 320 readout samples (fixed FOV), respectively.

**METHODS** Healthy human volunteers (N=12) were imaged on a 3T scanner (Siemens Verio). Two FPP scans (SR-prepared FLASH) were performed at rest (>10 minutes gap) using a single-shot radial pulse sequence followed by a single-shot Cartesian sequence (common parameters: FOV read =270-350 mm; BW ≈800 Hz/pixel; flip angle = 12°; TR =2.4-2.6 ms; TI =100 ms). Both scans were accelerated using rate 2 parallel imaging (TGRAPPA for Cartesian and SENSE for radial) and the number of readouts per frame was matched within 10% (range: 48-56). Scans were visually read for artifact by 2 expert readers blinded to the study protocol using a consensus 0-4 scoring scheme (0: no DRA; 4: severe DRA). To verify the described PSF effects, a realistic MR phantom shown in Fig. 2a (Gelatin-based with realistic contrast ratios) was built and imaged using similar sequence settings as above and the same number of readouts and scan time for the Cartesian and radial acquisition.



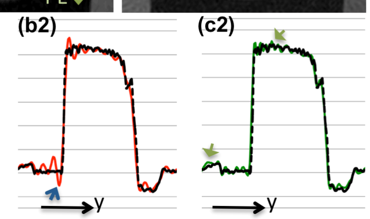




**Fig 2.** Reconstructions results for the MR phantom in (a) with 77 readouts (256 readout samples). **(b1)** shows the Cartesian reconstruction with 1.5x3.0 $mm^2$ resolution (FOV size = 384x230 $mm^2$) and **(b2)** shows the corresponding 1D cut along y; arrows in (b1)-(b2) point to DRAs. **(c)** shows the radial reconstruction with 1.5x1.5 $mm^2$ resolution and **(c2)** shows the 1D cut; arrows in (c2) point to mild streaking artifacts.

**RESULTS** Fig. 2 shows the results of the phantom study verifying the described PSF effects (details in caption). In contrast to the radial image in (c1-2), the Cartesian image in (b1-2) shows significant ringing. Representative images from 2 of the 12 studied subjects are shown in Fig. 3, where the top panels show Cartesian images (arrows point to DRAs) and bottom ones are the corresponding radial images. All images correspond to a pre-defined early myocardial enhancement phase (see caption). Qualitative analysis (Fig. 3c) clearly shows the superiority of radial imaging in reducing the DRA (2.83±0.8 vs. 0.24±0.32). Similar findings were evident from quantitative assessment of the DRA maximal width, shown in Fig. 3d (3.28±0.46 vs. 0.58±0.47).

**CONCLUSIONS** We demonstrated that radial imaging is capable of significantly reducing the dark rim artifact even in the early myocardial enhancement phase of a first-pass perfusion image series, due to its inherent robustness to Gibbs ringing. Such artifacts may be mistaken for subendocardial perfusion deficits or, alternatively, may result in missing the subendocardial defects that “fill in" during the early myocardial enhancement phase [1]. Advanced (e.g., model-based/iterative) reconstruction techniques with radial acquisition can be used to improve image quality while preservin the described dark-rim-minimizing properties.

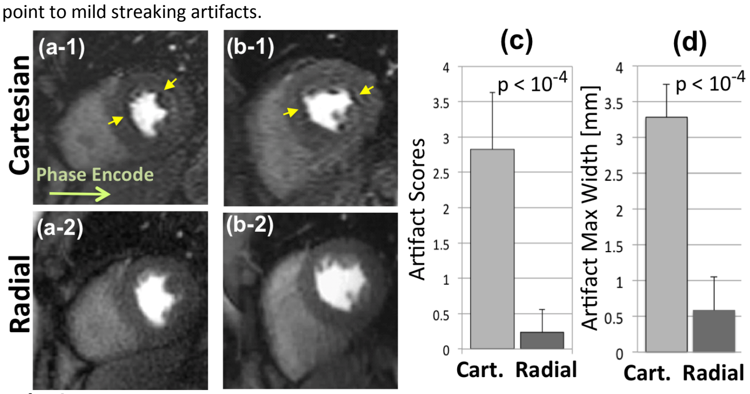



**Fig 3.** Representative first-pass myocardial perfusion images from 2 of the 12 studies healthy human volunteers; all images correspond to a similar early myocardial enhancement phase (7 heart beats after initial LV cavity enahncement). **(a-1), (b-1)** show the Cartesian images and **(a-2), (b-2)** show the corresponding radial images. **(c), (d):** summary of artifact scores (qualtiative and quantititive, respectively).

**REFERENCES** [1] Gerber et al., JCMR 2008;10:18. [2] DiBella et al., MRM 2005;54:1295. [3] Ferreira et al., MRM 2008;60:860. [4] Ferreira et al., JCMR 2009;11:17. [5] Sharif et al., JCMR 2012;14(Sup.1): P275. [6] Lauzon and Rutt, MRM 1996; 36:940.