

# Optimization of Spiral Pulse Sequences for First-Pass Myocardial Perfusion Imaging

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**Introduction:** Assessment of myocardial perfusion during adenosine stress is commonly used to evaluate patients with suspected coronary artery disease. First-pass perfusion imaging using MRI is used clinically, but dark-rim artifacts (DRA), which may be mistaken for true perfusion abnormalities, remain a challenge. As these artifacts are at least in part related to the effects of cardiac motion during data acquisition, spiral trajectories which are relatively insensitive to motion, may be less susceptible to DRA. Spiral trajectories have other attractive features such as efficiency in traversing k-space, isotropic resolution and point-spread functions, and the lack of discrete ghosting resulting from motion, but they are susceptible to off-resonance artifacts. Spiral pulse sequences have only recently been applied to myocardial perfusion imaging.[1,2] We have demonstrated the feasibility of obtaining high quality perfusion images using spiral pulse sequences at 1.5T [2]. The goal of this project was to evaluate how variations in the readout duration per interleaf, number of spiral interleaves, and spatial resolution affect the image quality and artifacts for first-pass myocardial perfusion imaging using spiral trajectories in human subjects.

**Methods:** Resting spiral perfusion imaging was performed in 32 patients who were undergoing clinically ordered CMR studies with contrast under an IRB approved protocol. Imaging was performed on a 1.5T MR Scanner (Magnetom Avanto, Siemens Medical Solutions). To avoid confusion between dark-rim artifacts and true perfusion abnormalities, all of the patients had low likelihood of coronary artery disease, and none of the patients had wall motion abnormalities or evidence of myocardial scarring by delayed enhancement imaging. Fifty images were obtained at 3 slice locations during injection of 0.1 mmol/kg Magnevist (Bayer Pharmaceuticals) via a peripheral IV at a rate of 4mL/sec using a saturation recovery (SR) slew-limited interleaved spiral pulse sequence (Figure 1). Low resolution field maps were obtained using two single-shot spiral images for off resonance correction with each perfusion image. The flip angle was chosen to have nearly constant magnetization on each interleaf for the given SR time, TR, and expected myocardial T1 values.[2] Common sequence parameters included a SR time of 80 ms, TE 1.5 ms, slice thickness 10 mm, FOV 320-340 mm depending on patient size, TR minimized for the particular readout duration. 12 patients were imaged with a spiral pulse sequence with 8 interleaves with a readout time of 8.1 ms, and a spatial resolution of 2.18mm<sup>2</sup> which served as the reference pulse sequence. To evaluate the effects of readout duration on image quality 8 subjects were imaged with pulse sequences with the same spatial resolution but shorter (6.5ms 10 interleaves, N=4) or longer (10.8ms, 6 interleaves, N=4) readout times. For these experiments the spatial resolution and total data collection time were held constant between pulse sequences. To evaluate the effects of image resolution, 10 subjects were imaged with a resolution of 2.63mm<sup>2</sup> with a 6-interleaf pulse sequence with the readout duration equal to that of the 8-interleaf pulse sequence so that off-resonance performance would be similar. Images were reconstructed using semi-automatic reconstruction with Chebyshev approximation of the off-resonance phase term. The SNR for each study was measured at peak ventricular and myocardial enhancement. All image series were evaluated for off-resonance, dark-rim, signal dropout, and fat-suppression artifacts. Image quality was graded on a 5-point scale (1-excellent, 5-poor) independently by two highly experienced cardiac imagers.

**Results:** High quality perfusion images were successfully obtained in all subjects. Figure 2 demonstrates first-pass images at peak LV enhancement from one subject using the 8-interleaved pulse sequence; the images have high SNR and minimal dark-rim or off resonance artifacts. The SNR of the LV cavity and myocardium for the 6, 8, and 10 interleaved pulse sequences with 2.18mm resolution were 54.7 ± 13.6 and 22.0 ± 5.6, 52.6 ± 13.7 and 21.3 ± 4.2, and 38.5 ± 6.2 and 13.6 ± 3.5 respectively. The SNR of the 6 and 8 interleaved pulse sequences were similar, but the 10 interleaved pulse sequence had significantly lower SNR consistent with theoretical predictions. The average image quality scores for the 6, 8, and 10 interleaved pulse sequences were 1.3, 1.35, and 1.65 respectively. The 6-interleaved pulse sequences had the least dark-rim artifacts (6% mild DRA), but 18% of the studies had at least mild blurring due to the reduced off resonance performance of this pulse sequence due to the longer spiral readout. The 10-interleaved pulse sequence had the least blurring, but the 8 and 10 interleaved pulse sequences had more images with at least mild DRA. Thus, sequences with fewer interleaves reduce DRA, but the readout time must be kept relatively short to avoid off-resonance blurring.

For the resolution experiment, the SNR of the LV cavity and myocardium for the 6- interleaved pulse sequence with 2.63mm<sup>2</sup> resolution were 61.4 ± 17.6 and 22.0 ± 5.6 respectively, which was not statistically greater than that of the reference pulse sequence. Furthermore, the average image quality score was 1.55, which was less than that of the reference pulse sequence primarily due to a high number of images with dark-rim artifacts, and image blurring. The increased number of images with at least some DRA supports that concept that a component of the DRA is explained by Gibbs-ringing due to the finite resolution of the perfusion imaging pulse sequence. This demonstrates the importance of using some of the spiral efficiency to improve spatial resolution to combat the DRA.

**Conclusion:** This study demonstrates that high-quality first-pass perfusion images of clinical patients can be obtained with non-parallel interleaved spiral trajectories. With this non-parallel interleaved spiral pulse sequence 3 slices can be imaged at heart rates up to 110 bpm with an SR time of 60ms. The implementation of variable density trajectories and parallel imaging strategies should provide additional benefits towards reducing the dark-rim artifact and further improving imaging speed allowing longer saturation times and higher SNR.

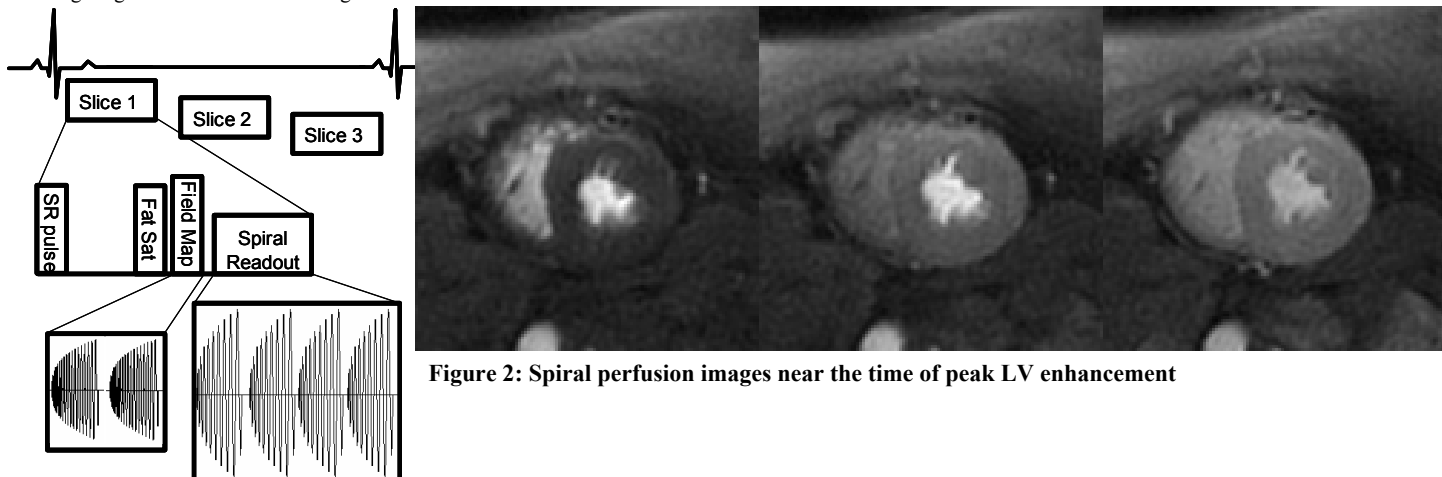


Figure 2: Spiral perfusion images near the time of peak LV enhancement

Figure 1: Schematic of Interleaved Spiral Perfusion Pulse Sequence

1. Shin et al. Proceedings 11<sup>th</sup> SCMR Scientific Sessions, 2008
2. Salerno et al. ISMRM Non-Cartesian Workshop, Sedona AZ, 2009.