Myocardial Perfusion Imaging with Variable Density Spiral Trajectories

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Introduction: Adenosine stress MR perfusion imaging is frequently used to evaluate patients for the presence of obstructive coronary artery disease, but may suffer from dark-rim artifacts (DRA) which may be mistaken for true perfusion abnormalities. Variable density (VD) spiral trajectories are an efficient method for data acquisition and may be advantageous for first pass myocardial perfusion imaging as they are robust to motion which may contribute to the DRA. Furthermore, by designing the trajectory and density compensation function appropriately, VD trajectories can also be used to reduce side lobe amplitude [1] which should reduce Gibbs ringing in the image which is also a contributing factor to the DRA. The goal of this project was to design and implement a VD spiral pulse sequence for first-pass myocardial perfusion which should further reduce sensitivity to dark rim artifacts, and evaluate the pulse sequence in a clinical setting.

Theory: Conventional uniform density (UD) spirals have uniform spacing of 1/FOV between the spiral arms (Fig 1a, red), but non-uniform density along the spiral trajectory due to the finite slew of the gradient amplifiers of the scanner. This non-uniformity along the trajectory is generally compensated for during reconstruction with an appropriate density compensation function (DCF) (Fig 1b,red) VD spirals (Fig 1a,blue), in addition to the non-uniform density along the trajectory, also have non-uniform spacing of the spiral arms with decreasing density near the outer regions of k-space resulting in a higher resolution image for the same readout duration (or conversely an image with the same spatial resolution and decreased readout time and thus improved off resonance performance). If the VD data is compensated with a DCF that is the inverse of its density (Fig 1b, blue), there will be a reduction in SNR due to the significant non-uniform weighting of noise in k-space. However if the VD spiral data is instead weighted by the corresponding UD-DCF (Fig 1b,red) which "under corrects" the density, there will be more uniform weighting of noise in k-space and the images will have higher SNR. This correction will cause the effective k-space weighting shown in figure 1c, which results in a smooth windowing of the k-space data that should reduce Gibbs ringing and thus potentially reduce DRA at the cost of some reduction in image resolution.
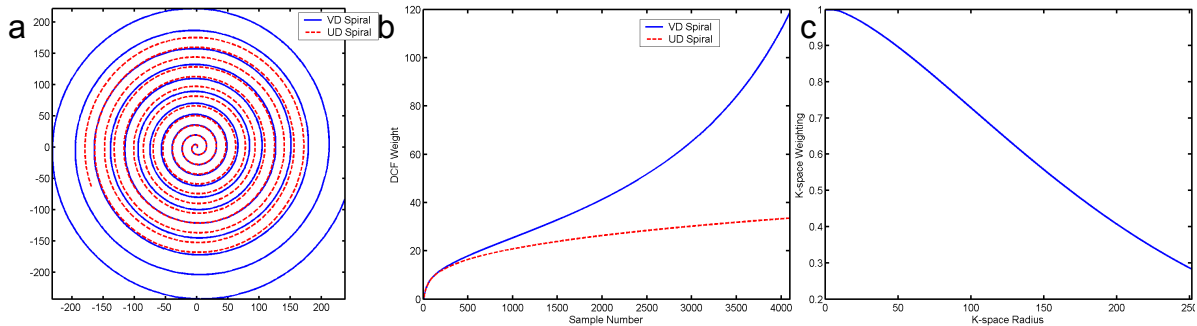

Figure 1

Methods: An interleaved, linear in time VD spiral trajectory was designed with an initial relative density of 1.2 and a final relative density of 0.4 (where 1 corresponds to Nyquist sampling). Sequence parameters included saturation recovery (SR) time of 80 ms, TE 1.5 ms, TR 11 ms, TH 10 mm, FOV 320mm, 6 interleaves, 8.1 ms readout duration, nominal spatial resolution of 2.13 mm^2. 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.[3] Images were reconstructed with linear off-resonance correction using both the UD and VD DCFs. Point spread functions (PSF) were evaluated for both of these reconstructions. Resting spiral perfusion imaging was performed in 6 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 VD spiral pulse sequence.

Results: Figure 2 shows the PSFs when images are reconstructed with the VD or UD DCFs. The full-width-half-maximum (FWHM) of the UD-DCF weighted PSF is 11% wider than that of the VD-DCF-weighted PSF, but there is a 58% reduction in amplitude of the first side-lobe. Figure 3 demonstrates images after using the variable-density DCF and the uniform-weighted DCF respectively. In the images where the actual VD-DCF is used, there is higher resolution with significantly reduced SNR. However, when the uniform-density DCF is used instead for density compensation of the same data, there is improved SNR, and further reduction of dark-rim artifacts.

Conclusions: VD spiral perfusion pulse sequences, when reconstructed with a corresponding UD-DCF, result in myocardial perfusion images with increased SNR and reduced DRA with only an 11% reduction in image resolution. Using this sequence high quality perfusion images can be obtained at 3 slice locations with a SR time of 80 ms for heart rates up to 115 bpm thus providing adequate temporal resolution for adenosine stress CMR imaging, and further testing in this clinical setting is warranted
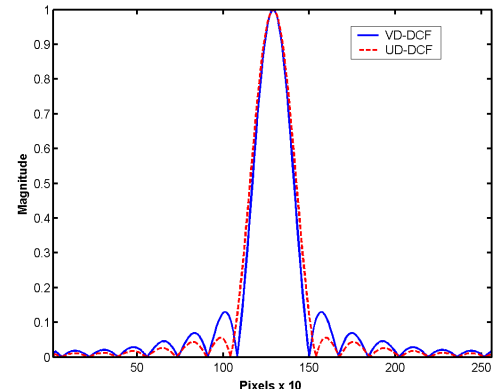

Figure 2: PSF from VD spiral trajectory corrected with the VD-DCF (blue) or the UD-DCF (red)
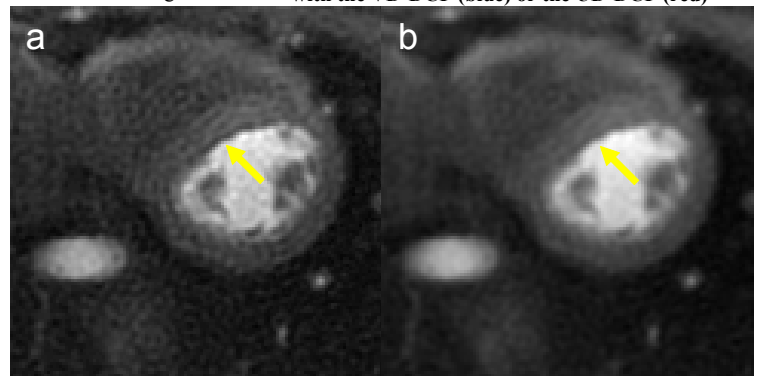

Figure 3: Perfusion Images reconstructed with (a) VD DCF have lower SNR and worse DRA than those reconstructed with the (b) UD DCF

References:
1. Adalsteinsson E et al. *Magn Reson Med.* 1999;42(2):314.
2. Liao et al. *Magn Reson Med* 1997; 37:569
3. Salerno et al. ISMRM Non-Cartesian Workshop, Sedona AZ, 2009.