An Alternating Partial Fourier k-space Segmentation Scheme for Imaging of Myocardial Delayed Enhancement

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Purpose: Myocardial delayed enhancement (MDE) is commonly used to assess viability of myocardial tissue. An ECG gated, segmented inversion recovery (IR) fast gradient recalled echo (FGRE) or a steady-state free precession (SSFP) sequence is used for imaging, 15-20 minutes after administration of Gadolinium-based contrast. Multiple slices are typically acquired in successive breath-holds. Single shot methods have been proposed to reduce the BH duration at the cost of poor spatio-temporal resolution. In order to minimize sensitivity to inversion time selection, phase sensitive inversion recovery (PSIR) techniques have been proposed [1] which acquire a reference phase correction dataset, further doubling the scan time. In this work, we investigated the use of a time efficient alternating partial Fourier (APF) k-space segmentation strategy.

Methods: In conventional MDE imaging, k-space is segmented into interleaves and each interleaf is acquired in a separate R-R interval, following the 180° pulse. In our proposed APF segmentation scheme, k-space was partitioned into two halves, each extending N_{over} views beyond the center of k-space. Each half was acquired sequentially (Fig 1), alternating in direction between the two halves, resulting in full k-space coverage. The central $2*N_{over}$ k-space lines are signal averaged [2], offering both motion immunity and an SNR increase without doubling the acquisition window. This combination also obviated the need for partial Fourier reconstruction, improving image quality. In order to increase temporal resolution, each half k-space segment can be further interleaved into sub-segments. Parallel imaging could instead be used to reduce the acquisition window within the R-R interval without increasing scan time but at the cost of reduced SNR. The signal averaging afforded by the APF scheme offsets some SNR loss due to parallel imaging.

MATLAB simulations were performed to compare the effects of motion on conventional interleaving and the proposed APF segmentation scheme. A displacement of 4 pixels in the phase encoding direction (L/R) was introduced half way into the second R-R. The APF scheme was incorporated into an IR FGRE and a PSIR FGRE sequence. Pulse sequence parameters were as follows: bandwidth ±41.7 kHz, 20° flip angle, TR/TE 4.7/2.1ms, 192x128 matrix, 38x34cm FOV, 8 mm slice thickness, 2-4 R-R intervals per slice, 40 k-space encodes per RR (SENSE factor 2 was used when acquiring over 2 R-R for PSIR). A high spatial resolution PSIR sequence with conventional interleaved view ordering (224x160 matrix, 24-32 k-space encodes per R-R, ±32 kHz BW, TR/TE 6.1/2.8ms) was also acquired for comparisons. Fifteen patients were scanned on a GE HDx 1.5T (GE Healthcare, Waukesha, WI) scanner with an 8-channel cardiac phased array coil under an IRB approved protocol. MDE imaging started 15 minutes following 0.2 mmol/kg/min injection of Gd-DTPA. Three breath holds of 2-3 slices per breath hold were performed covering short axis and radial long axis views of the heart. All images were reviewed by a board certified radiologist, who rated the overall image quality, degree of artifacts and perceived SNR on a scale of 1-4 (worst-best). A Mann-Whitney test was used to determine statistical significance.

Results: Figure 2 shows MATLAB simulations of the effects of motion on image quality using the proposed APF scheme (a) and a conventional interleaved acquisition (b). Note the significant reduction in motion artifacts and reduced blurring in (a) compared to (b). Figure 3 shows representative short axis images obtained using the high resolution, 4 R-R APF, and 2 R-R APF PSIR sequences in a patient with an infarct in the anterior left ventricle (arrows). For overall image quality and artifacts, there were no significant differences in image scores between the conventional high resolution PSIR sequence and either the 2 R-R or the 4 R-R PSIR APF sequences. The perceived SNR was significantly better for both 2 R-R and 4 R-R PSIR APF sequences compared to the high resolution PSIR sequence (p<0.05). Similar trends were observed for the non-PSIR MDE sequences as well.

Conclusion: We have demonstrated the use of an alternating partial Fourier k-space segmentation scheme for time efficient MDE imaging. It is an optimal trade-off between conventional MDE imaging and single-shot imaging. The signal averaging of just the central k-space lines has added benefits of reducing motion artifacts without doubling the scan time, counteracting some of the SNR loss experienced from parallel imaging and could potentially be used for self-navigated motion correction. The use of a balanced SSFP sequence instead of FGRE would further improve image SNR and temporal resolution.

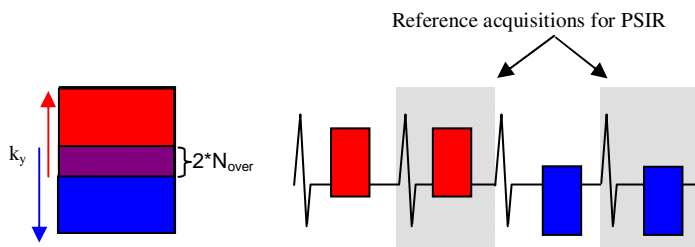**References**: [1] Kellman et al. MRM 2002. 47:372-383 [2] Reynolds et al. Proc ISMRM 2005; 1643

Figure 1. Schematic for the proposed APF MDE acquisition. Top (red) and bottom (blue) halves of k-space with a small overlap (purple) are acquired on successive R-R intervals and combined.

Fig 2. Shepp-Logan phantom simulations demonstrating motion robustness of the proposed APF scheme (a) compared to an interleaved acquisition (b)
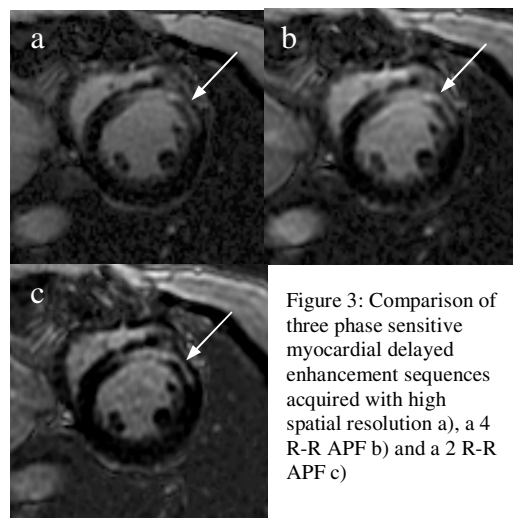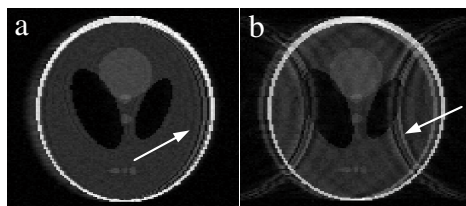

Figure 3: Comparison of three phase sensitive myocardial delayed enhancement sequences acquired with high spatial resolution a), a 4 R-R APF b) and a 2 R-R APF c)