Journal of Cardiovascular Magnetic Resonance

BioMed Central

Meeting abstract

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213 Optimally undersampled variable density spiral trajectories applied to real-time cardiac MRI at 3 Tesla

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from 11th Annual SCMR Scientific Sessions
Los Angeles, CA, USA. 1–3 February 2008

Published: 22 October 2008

Journal of Cardiovascular Magnetic Resonance 2008, **10**(Suppl 1):A74 doi:10.1186/1532-429X-10-S1-A74

This abstract is available from: http://jcmr-online.com/content/10/S1/A74

Introduction

Conventional uniform density spiral trajectories are time-efficient in covering k-space, but may not satisfy the temporal and spatial resolution requirements of applications such as real-time coronary artery imaging [1]. Undersampled variable density spirals have the potential to meet the speed requirements, but after gridding reconstruction, aliasing artifacts from the undersampled high spatial frequencies may hamper the evaluation of anatomic structures. Recently, L1-norm regularized iterative reconstruction [2] has been proposed as a methodology for producing exact images from sparsely sampled Fourier data. In order to achieve the required incoherence of spatial aliasing, we propose the optimization of variable density spiral (VDS) trajectory based on its point spread function (PSF). We demonstrate the effectiveness of optimized VDS acquisition and regularized iterative reconstruction in real-time cardiac MRI at 3 Tesla.

Methods

We considered VDS trajectories where sampling density, i.e. field-of-view (FOV), monotonically decreases with k-space radius (k_r). A set of VDS trajectories with linear and quadratic variations in sampling density was considered. The spatial resolution, readout duration, and number of interleaves were kept constant. Monte-Carlo simulations were performed to determine the VDS trajectory that minimizes the maximum sidelobe in magnitude of the PSF (Fig. 1).

Regularized iterative reconstruction based on non-linear conjugate gradient algorithm was performed to minimize a cost function, which consists of data consistency and total variation terms [2]. A total variation penalty was used to preserve edges and remove aliasing artifacts resulting from the undersampling of high spatial frequencies. Non-uniform FFT [3] was used in the conjugate gradient algorithm to accelerate reconstruction time while efficiently managing memory use.

In-vivo experiments were performed in healthy volunteers on a GE Signa Excite 3 T scanner using an eight-channel cardiac receiver coil. A custom real-time imaging platform was used to interactively adjust scan parameters and acquire cardiac data [4]. Imaging parameters were: spectral-spatial excitation, 5.0-mm slice thickness, 60-deg flip angle, 96-ms temporal resolution, $1.1 \times 1.1\text{-mm}^2$ spatial resolution, 6.4-ms readout duration, 8-interleaves. Three different undersampled gradient-echo spiral imaging protocols were tested: 1) uniform density spiral with FOV 10-cm, 2) optimal VDS with linearly decreasing sampling density, and 3) optimal VDS with quadratically decreasing sampling density. Identical shim values were used for all acquisitions.

Results

Figure 2 contains real-time right coronary artery (RCA) images obtained within a diastolic cardiac phase from a healthy volunteer. Under the same spatial and temporal resolution requirements, optimal VDS acquisitions (Fig. 2b,c,e,f) substantially reduced aliasing artifacts compared to uniform density spiral acquisitions (Fig. 2a,d). The iterative reconstruction removed residual aliasing artifacts,

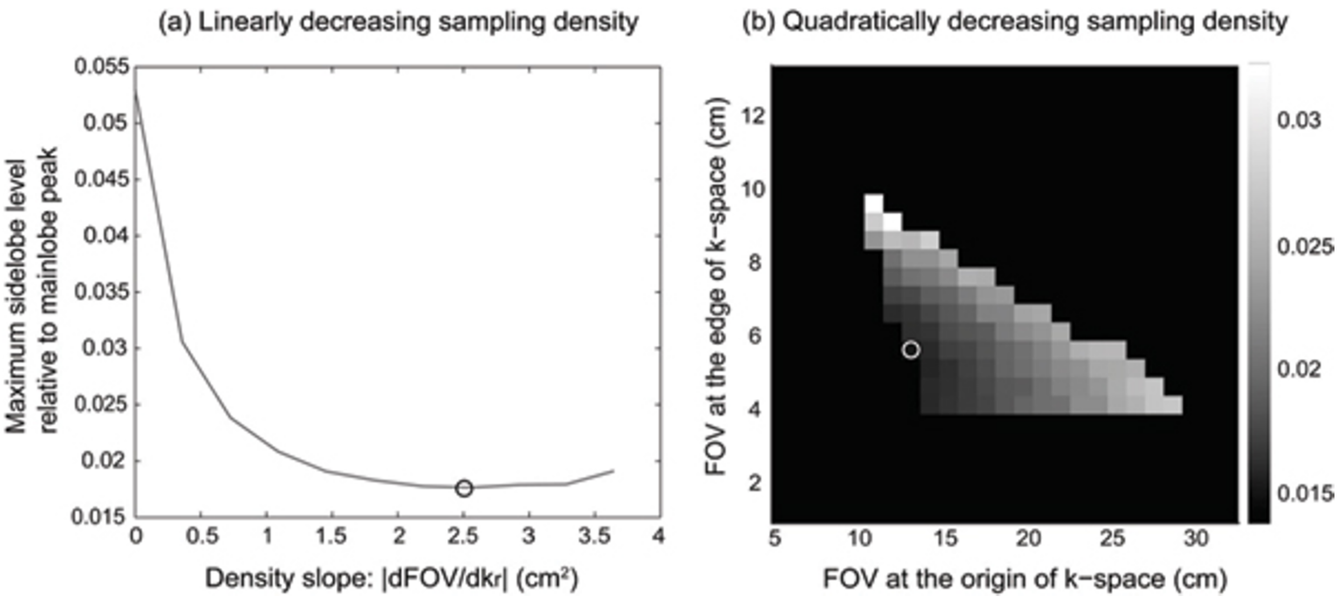

Figure 1
Maximum PSF sidelobe magnitude. Optimal density variations are identified by circles. Note that maximally dense sampling of low spatial frequencies does not lead to optimal suppression of sidelobe peak.

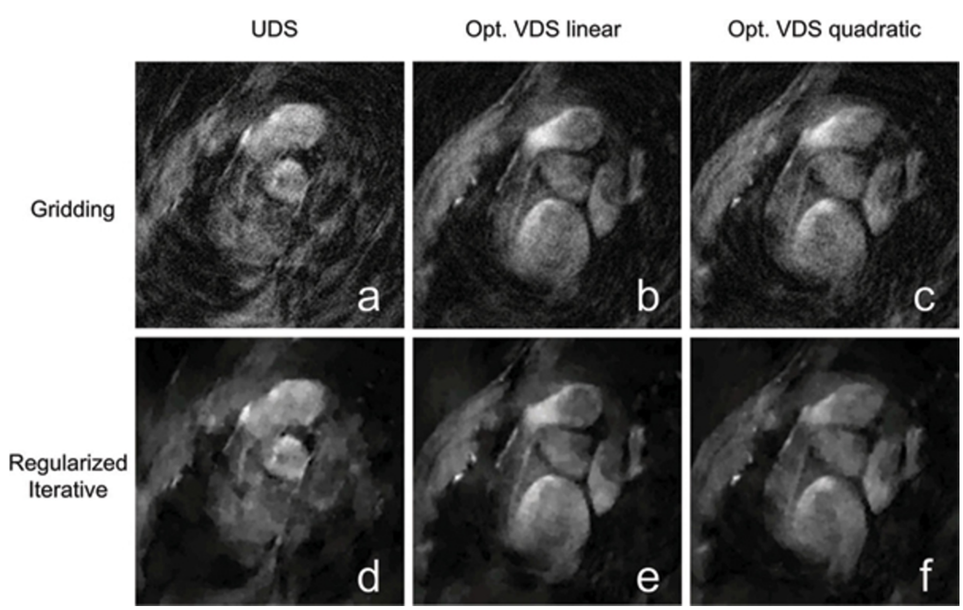

Figure 2
Variable-density spirals can be optimized for incoherence of spatial aliasing artifacts, and iterative reconstruction from optimally undersampled data produces images with substantially reduced aliasing. This technique is applied to real-time cardiac MRI at 3-Tesla, and is compared with uniform-density spirals. Real-time RCA images obtained in a healthy volunteer at 3 Tesla. Uniform density spiral trajectories experience severe aliasing artifacts (a, d). Both optimally chosen VDS trajectories produce comparable image quality (b, c, e, f) with a clear depiction of the right coronary artery. Regularized iterative reconstruction (e, f) produces images with reduced aliasing artifacts and higher SNR compared to gridding reconstruction (b, c).

which are visible in gridding reconstruction (compare Fig. 2b and 2e, also Fig. 2c and 2f).

Discussion and conclusion

Regularized iterative reconstruction, when combined with optimally chosen VDS sampling trajectories, effectively reduces aliasing artifacts and is qualitatively superior to gridding reconstruction. However, iterative reconstruction remains relatively slow, and is not yet compatible with real-time reconstruction.

References

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