LMU KLINIKUM DER UNIVERSITÄT MÜNCHEN

Three-dimensionally accelerated radial parallel MRI with a 32-channel coil system

Olaf Dietrich <od@dtrx.net>, Maria Suttner, Maximilian F. Reiser

Josef Lissner Laboratory for Biomedical Imaging, Department of Clinical Radiology – Großhadern, LMU Ludwig Maximilian University of Munich, Germany
<http://www.radiologie-lmu.de>

Introduction

Background: Established parallel-imaging techniques include the one-dimensional or two-dimensional acceleration of data acquisition with Cartesian or non-Cartesian trajectories [1–4]. However, state-of-the-art receiver coil arrays with 32 and more coil elements that are distributed approximately uniformly in space should also enable a three-dimensional (3D) parallel-imaging acceleration, i. e., simultaneous sparse sampling in all three k-space directions.

Problem: Unfortunately, a reduced sampling density in the frequency-encoded (readout) direction cannot be efficiently employed for scanning acceleration. Thus, simultaneous parallel-imaging in all three spatial directions requires either acquisition techniques without spatial frequency encoding (e. g., chemical-shift imaging) or techniques with varying frequency-encoding directions.

Purpose: The purpose of this study was to demonstrate 3D accelerated parallel-imaging with high acceleration factors based on a 3D radial gradient-echo sequence.

Methods

MR hardware: A fast gradient-echo pulse sequence with 3D radial trajectories was implemented on a 3-Tesla 32-channel MRI system (Magnetom Tim-Trio, Siemens Healthcare, Erlangen, Germany) equipped with a 32-channel cardiac array consisting of a flexible anterior part with 16 elements and a posterior part with 16 elements (Rapid Biomedical, Rimpar, Germany).

k-space trajectory: The radial k-space trajectories were distributed approximately uniformly in all spatial directions within a 3D sphere (Fig. 1). The number of radial readouts of the non-accelerated trajectory was chosen such that the Nyquist condition was fulfilled on the surface of the sphere; consequently the center of k-space was substantially oversampled. Accelerated trajectories were obtained by uniformly removing readouts, i. e., by reducing the number of used zenith and azimuth angles.

Sequence parameters: The pulse sequence was optimized for fast imaging of a cubic field of view (FOV) with isotropic resolution. Phantom images were acquired with TE=1.13 ms, TR=2.58 ms, flip angle of 8°, FOV=$384 \times 384 \times 384\,\text{mm}^3$, and 128 samples/readout including factor-2 oversampling. The parallelimaging acceleration factor was $R = 32$ (equal to the number of used coil elements), resulting in 209 radial readouts for a reconstructed matrix size of $64 \times 64 \times 64$.

Reconstruction: Image data were iteratively reconstructed with a conjugate-gradient SENSE algorithm [4] generalized for 3D trajectories and 3D data sets. Coil sensitivity maps were estimated with 3D polynomial fits of order 4 from the sum-of-squares reconstruction of the undersampled data sets. We used an overgridding factor of 2 and stopped the reconstruction after 5 iterations.

Results

Images: Reconstructed data sets are shown in Figs. 2 and 3. The conventional sum-of-squares reconstruction (without application of parallel imaging reconstruction algorithms) is blurry due to severe undersampling of the k-space periphery (Fig. 2a). Image quality is substantially improved after CG-SENSE reconstruction (Fig. 2b) based on the measured coil sensitivity profiles.

Measurement time: The full 3D data set (64 slices with 64×64 matrices and isotropic $6 \times 6 \times 6\,\text{mm}^3$ resolution) was acquired in $209 \times 2.58\,\text{ms} = 540\,\text{ms}$. The effective acceleration factor compared with a Cartesian acquisition of a $64 \times 64 \times 64$ matrix was $(64 \times 64)/209 \approx 20$ due to the oversampling of the k-space center.

Memory requirements: The reconstruction required relatively large amounts of memory for complex-valued coil profiles and reconstructed image data (more than 1 GiByte).

Conclusions

Very high parallel-imaging acceleration factors can be used in radial sequences with uniformly distributed three-dimensional undersampling. A potential application of the suggested technique is, e. g., perfusion MRI of the head, the lungs, or the abdomen with sub-second temporal resolution. Faster and less memory-intensive reconstruction methods such as k-space-based reconstruction techniques are required for the processing of data sets with larger matrix size of, e. g., $128 \times 128 \times 128$ or $192 \times 192 \times 192$.

References

[1] Pruessmann KP et al. SENSE: sensitivity encoding for fast MRI. Magn Reson Med 1999;42:952–962.
[2] Weiger M et al. 2D SENSE for faster 3D MRI. MAGMA 2002;14:10–19.
[3] Breuer FA et al. Controlled aliasing in volumetric parallel imaging (2D CAIPIRINHA). Magn Reson Med 2006;55:549–556.
[4] Pruessmann KP et al. Advances in sensitivity encoding with arbitrary k-space trajectories. Magn Reson Med 2001;46:638–551.

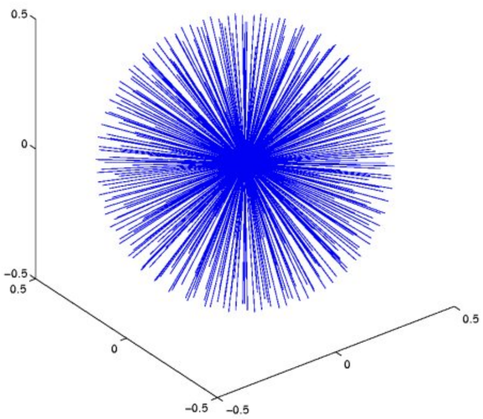

Fig. 1: Three-dimensional, undersampled isotropic *k*-space trajectory. 209 radial readouts are distributed uniformly within a sphere in *k*-space.

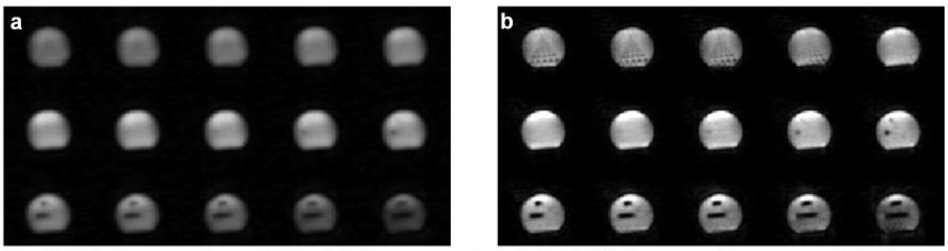

Fig. 2: Detail comparison of 15 axial slices reconstructed with (a) the sum-of-squares and (b) the CG-SENSE technique. Data was acquired with a (nominal) acceleration factor of *R*=32.

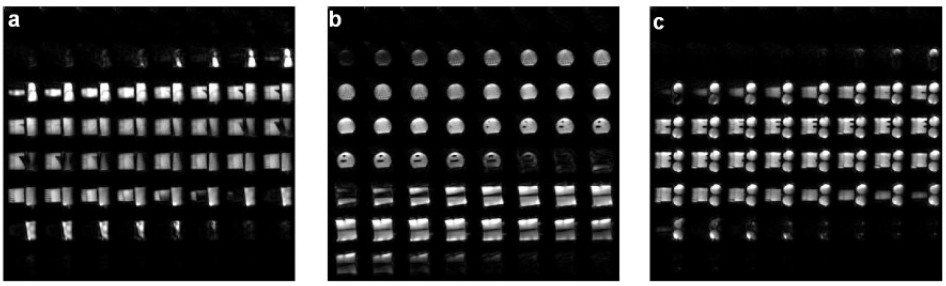

Fig. 3: Complete data set of 64 slices reconstructed with CG-SENSE: (a) sagittal, (b) axial, (c) coronal.