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

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Introduction: 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. 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. 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: 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). 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.

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=384×384×384 mm³, and 128 samples/readout including factor-2 oversampling. The parallel-imaging acceleration factor was R=32 (equal to the number of used coil elements), resulting in 209 radial readouts for a reconstructed matrix size of 64×64×64.

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: 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. The full 3D data set (64 slices with 64×64 matrices and isotropic 6×6×6 mm³ resolution) was acquired in 209×2.58 ms = 540 ms.

The reconstruction required relatively large amounts of memory for complex-valued coil profiles and reconstructed image data (more than 1GiByte). The effective acceleration factor compared with a Cartesian acquisition of a 64×64×64 matrix was (64×64)/209 ≈ 20 due to the oversampling of the *k*-space center.

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. 128×128×128 or 192×192×192.

References: **[1]** Pruessmann KP et al. SENSE: sensitivity encoding for fast MRI. Magn Reson Med 1999;42:952-62. **[2]** Weiger M et al. 2D SENSE for faster 3D MRI. MAGMA 2002;14:10-9. **[3]** Breuer FA et al. Controlled aliasing in volumetric parallel imaging (2D CAIPIRINHA). Magn Reson Med 2006;55:549-56.
[4] Pruessmann KP et al. Advances in sensitivity encoding with arbitrary k-space trajectories. Magn Reson Med 2001;46:638-51.

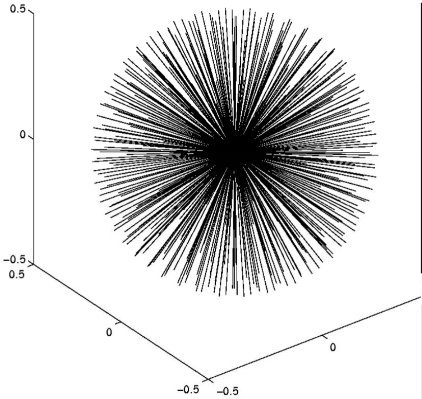

Fig. 1: Three-dimensional, undersampled isotropic *k*-space trajectory. 209 radial readouts are distributed uniformly within a sphere in *k*-space.

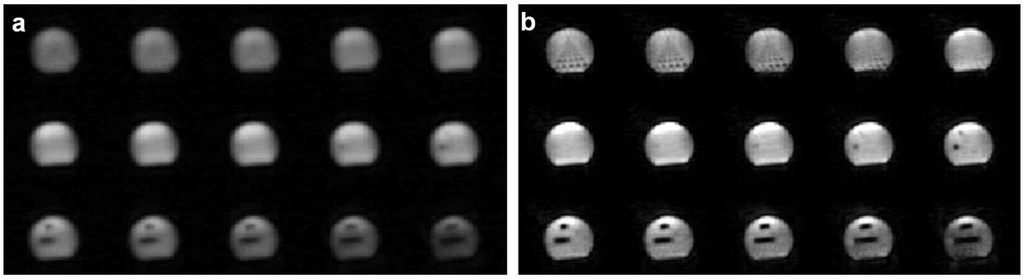

Fig. 2: Detail comparison of 15 axial slices reconstructed with (a) sum-of-squares and (b) CG-SENSE technique.

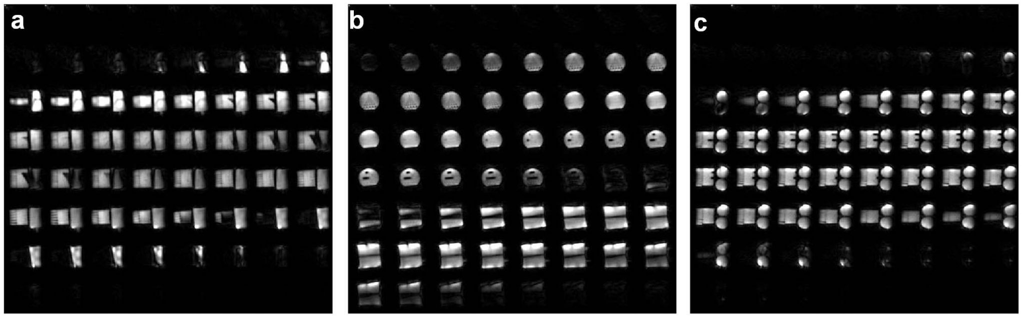

Fig. 3: Complete data set of 64 slices reconstructed with CG-SENSE: (a) sagittal, (b) axial, (c) coronal.