3D Radial Twisted Projection Imaging for DCE-MRI with Variable Flip Angles

P. Krämer[1], S. Konstandin[1], M. Heilmann[1], and L. R. Schad[1]
[1]Computer Assisted Clinical Medicine, Heidelberg University, Mannheim, Germany

Introduction

Radial acquisition schemes are used in dynamic contrast enhanced MRI (DCE-MRI) [1] due to superior motion insensitivity achieved by a repeated sampling of the *k*-space center each repetition time (TR). This also enables the use of *k*-space weighted image contrast (KWIC) [1] or sliding window reconstruction [2]. One disadvantage of radial acquisition schemes, especially in 3D imaging, is the high number of projections needed to fulfill the Nyquist criterion. Twisted projection imaging (TPI) [3] is a radial acquisition scheme which has been proposed for sodium imaging. The advantages of the *k*-space trajectory in TPI are ultra-short echo times (TE), density adapted sampling in radial direction, and a reduced number of necessary projections to fulfill the Nyquist criterion. In radial sequences with linear *k*-space trajectories, the Nyquist radius is the maximal sampled *k*-value. TPI reduces this radius by the factor *P*, where *P* is the fraction of *k*-space that is linearly sampled (Figure 1). A new sequence is presented which uses this advantage to reduce the number of necessary projections in 3D radial imaging. Since ultra-short TE is not needed in DCE-MRI two projections are acquired each TR further decreasing measurement time. Implementation is simplified by calculating only one trajectory with a given cone angle θ_{TPI} and rotating it every TR to cover the whole *k*-space. This technique requires fewer projections while maintaining image quality. Initial precontrast T_1 measurements are presented using a variable flip angle (VFA) [4] approach.

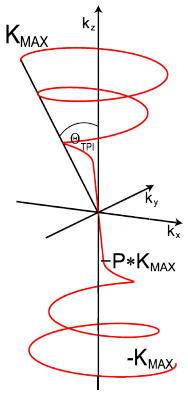

Figure 1: *k-space trajectory from K_{MAX} to $-K_{Max}$*

Methods

K-space Trajectory: Figure 1 shows the implemented *k*-space trajectory. The main modifications of our sequence with respect to the original implementation of TPI are the following: Two projections are acquired in one TR by dephasing at first to the maximum positive *k*-value K_{MAX} and then traversing k-space to the maximum negative *k*-value $-K_{MAX}$. To fulfill the Nyquist criterion the whole *k*-space has to be sampled sufficiently dense. In TPI, this is achieved by calculating a new *k*-space trajectory for each repetition. In this work, only one trajectory is initially calculated. The whole *k*-space is covered by rotating this trajectory by the angles (θ,φ) for each repetition. These angles are calculated using a recursive algorithm described by Rakhmanov et al. [5]. This implementation should yield similar results to the original TPI because of spherical symmetry.

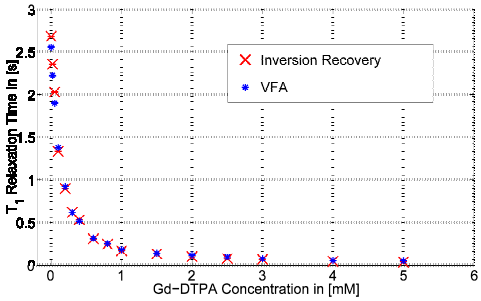

Figure 2: *T_1 phantom measurement. Comparison between inversion recovery spin-echo (red datapoints) and the 3D-VFA measurement (blue datapoints)*

Experiments: All experiments were performed on a Magnetom Skyra 3T MR system (Siemens Healthcare, Erlangen, Germany). The body coil was used for transmit to achieve maximum B_1 homogeneity for the VFA experiment. A 16-channel head coil was used for receive. All radial acquisitions had the following parameters in common: resolution: 1.5 mm isotropic; P=0.3; θ_{TPI}=15°; TE/TR: 4.2 ms/10 ms. T_1 relaxation times of a phantom containing different tubes with different concentrations of Gd-DTPA were measured with an inversion recovery spin-echo sequence in one slice (20 TI times from 0.03 s to 14s, TE/TR: 4 ms/ 15s) and with VFA with the optimized flip angles 3°, 14° and 16° for T_1=1.5 s and TR=10 ms [6]. A healthy male volunteer was scanned with the 3D TPI sequence and a standard 3D radial sequence. 3100 projections with 1152 samples each were acquired with the TPI sequence. These parameters were required to fulfill the Nyquist criterion for an isotropic field of view of 22 cm. The same number of projections has been used for the standard 3D radial sequence to retain the same measurement time. A VFA T_1-measurement was performed with the same flip angles as in the phantom experiment. The total acquisition time was 1 min 45 s.
Postprocessing: All postprocessing steps were performed in MATLAB. The raw data of each channel was interpolated on a Cartesian grid using a Kaiser-Bessel window before Fourier transformation. Signal to noise ratios (SNR) were calculated by dividing the mean signal of different region of interests (ROI) by the standard deviation of a ROI in the noise. Before fitting the T_1 maps, the datasets have been masked by thresholding. Fitting of the SPGR equation was performed using a Levenberg-Marquardt optimization algorithm.

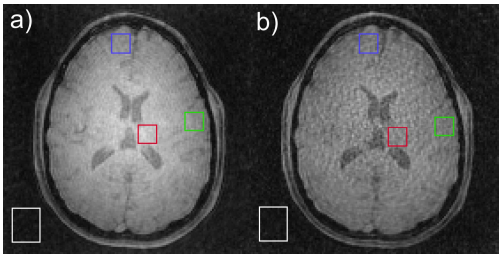

Figure 3: *Axial slices of the 3D datasets from the 3D TPI (a) and the standard 3D radial sequence (b)*

Results

The T_1 values measured with VFA are in good agreement with the values from the inversion recovery over a wide range of Gd-DTPA concentrations. Figure 2 shows the phantom T_1 measurement with inversion recovery (red dots) and VFA (blue dots). Only at higher T_1 times systematical deviations are noticeable. Figure 3 shows one axial slice of the 3D datasets acquired with the TPI sequence (a) and a standard 3D radial sequence (b). Both have been acquired with a flip angle of 3°. The standard deviation of the noise was taken from the white ROI. The SNR of the TPI sequence was compared to the standard radial 3D sequence (Table 1). Figure 4 shows an axial (a), coronal (b) and sagittal (c) slice of the VFA T_1-map of the volunteers head.

	TPI 3D	***standard 3D radial***
red ROI	35.4	19.8
green ROI	23.5	16.6
blue ROI	24.1	17.0

Table 1: *SNR of three ROIs. Comparison between TPI 3D and standard radial 3D sequence*

Discussion and Conclusion

This work shows the feasibility of fast 3D VFA T_1 mapping using a radial sequence with a TPI trajectory design. To our knowledge this sequence is the first TPI approach for proton MRI. Furthermore it has a higher SNR compared to normal radial sequences (Figure 3). VFA T_1 measurements are in good agreement with inversion recovery T_1 measurements over a large range of concentrations (Figure 2). Only at low concentrations, where T_1 is higher, deviations are visible because the flip angles have not been optimized for these T_1 times. An accurate 3D T_1 map of a human brain with an isotropic resolution of 1.5 mm can be acquired in 1 min 45 s. Especially in DCE-MRI this sequence has advantages for precontrast as well as dynamic measurements. It could be applied where conventional radial approaches to DCE-MRI suffer from lower SNR and undersampling artifacts. Using KWIC [1] or sliding window reconstruction, high temporal resolution could be achieved while maintaining image quality.

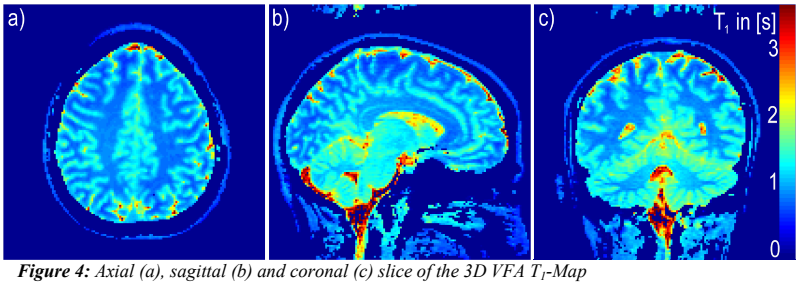

Figure 4: *Axial (a), sagittal (b) and coronal (c) slice of the 3D VFA T_1-Map*

References

[1] Lin W et al. Magn Reson Med 2008;60:1135–1146
[2] Winkelmann S et al. IEEE Trans Med Imaging 2007;26:68–76
[3] Boada F et al. Int J Imaging Syst Technol 1997;8:544–550
[4] Cheng HLM et al. Magn Reson Med 2006;55:566–574
[5] Rakhmanov EA et al. Mathematical Res Lett 1994;1:647–662
[6] Armitage P et al. Med Image Anal 2005;9:315–329