A Free-breathing Self-Gated 3D Golden-Angle Radial Technique for Abdominal Imaging and T1 Mapping

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Introduction

In 3D dynamic contrast-enhanced (DCE) MR imaging, a baseline T_1 map is required to assess tumor perfusion. Typically, several scans with different flip-angles are carried out during multiple breath-held periods to avoid respiratory motion artifacts. Although sufficient for 2D or 3D imaging with a limited number of slices, the scan time required for each data set could become prohibitive when greater number of slices or higher resolution (larger matrix size) is desired. Alternative means to compute T_1 maps that do not require breath-holding would therefore be of significant benefit. Such a technique would also be preferred for patients who may have difficulty with breath-holding for even short time periods.

Radial k-space sampling has recently been proposed for self-gated 2D cardiac cine MRI [1]. During a single breath-held scan, a set of azimuthally undersampled radial dataset is repeatedly acquired during one heart beat. During subsequent cardiac periods, similar undersampled datasets with slightly rotated angles are acquired, and this process continues until the azimuthal sampling density is sufficient. The repeated acquisition of the central k-space region allows for the detection of several possible "gating" signals, such as the echo magnitude, object center of mass or a low resolution image, which could be used to extract motion information. This information could then be utilized to separate the data into different cardiac phases for separate reconstruction [1]. Such technique has also been extended for free-breathing cardiac cine imaging [2]. One of the potential problems with respiratory self-gating is that since the respiratory period could vary substantially from cycle to cycle, sufficient azimuthal sampling density throughout entire k-space may not always be realized. In our present work, a self-gated golden-angle radial acquisition and reconstruction strategy is proposed for free-breathing 3D abdominal T_1 mapping.

Methods

A 3D hybrid radial sequence was modified from a fast gradient echo (3D FLASH) sequence. The inner slice-encoding loop (k_z) remained Cartesian, while the two in-plane axes (k_x, k_y) were modified for a golden-angle radial acquisition scheme. This scheme, in which a fixed angular offset of $\theta=111.25^0$ advances successive view angles, has the property that for any number of successive views chosen for reconstruction, k-space is approximately uniformly sampled in the azimuthal direction [3]. Furthermore, due to the pseudo-random sequence of view angles, selecting a non-contiguous subset of views also results in k-space sampling with well-distributed angular sampling.

3D coronal images of the abdomen were acquired from a normal volunteer, using a torso/spine coil array. Two separate 2-minute free-breathing scans were performed with flip angles $\theta_1=3^0$ and $\theta_2=13^0$, which were chosen to minimize the T_1 measurement error [4] assuming a nominal T_1 value of 500 ms. Scan parameters included: imaging volume 380x380x80 cm^3, 256 (readout) x 16 (slice) x 2048 (views), TE/TR 1.8/3.6 ms. The peak magnitude signal for each view angle at $k_z=0$ from one of the coils was smoothed using a 20-view window and low-pass filtered to derive a gating signal. The signal ratio of end-expiration phase image sets at two different flip angles was used to compute the T_1 map. An inverse FT was first taken along the z-axis to separate the slices for 2D regridding [5]. The 3D reconstruction took less than 1 minute on a 3.0 GHz Pentium PC.

Results and Discussion

Figure 1 shows a portion of the gating signal derived from the echo magnitude, representing the variation in the total transverse magnetization as organs move in and out of the coil sensitivity region due to respiration. Variations in peak heights and temporal durations for different respiratory cycles are consistent with results from prior studies [2], reflecting a higher degree of variation in respiratory motion compared to strictly cardiac motion [1]. Views corresponding to the end-expiration phase (circles) were used for the reconstruction and T_1 mapping. Since k-space is not uniformly sampled with the golden-angle scheme, local sampling density-dependent weightings of the data were applied prior to regridding. **Figure 2a** and **b** compares the self-gated and non-gated liver images (both radial, reconstructed using 512 views), showing a significant reduction of motion artifacts using the proposed self-gating method. **Figure 2c** is the T_1 map computed from the two scans at different flip angles. The results show that blurring at tissue boundaries and image streaking have been effectively removed with self-gating. It is straightforward to extend the proposed technique for T_1 mapping with more than two flip angles in order to improve measurement accuracy. It is also possible to reconstruct motion-free images or compute T_1 maps at other respiratory periods if desired. Future work will examine the utilization of other gating signals such as center-of-mass and spatial correlation of low resolution images. In conclusion, a free-breathing, self-gated radial technique based on the golden-angle scheme has been investigated for 3D abdominal imaging and T_1 mapping, and the results demonstrate that motion-induced blurring and streaking artifacts can be effectively removed.

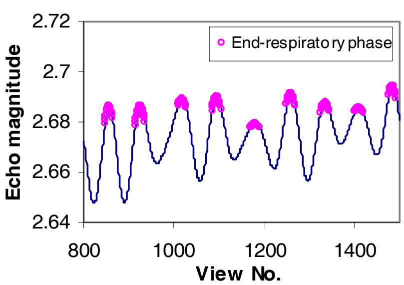

Fig. 1. The smoothed self-gating signal derived from the echo magnitude at $k_z=0$. Highlighted points correspond to end-respiratory views used for reconstruction and T_1 mapping.

Fig. 2. (a) End-respiratory image reconstructed from 512 radial views without self-gating. (b) Image reconstructed with self-gating. (c) T_1 maps (in ms) generated from two self-gating scans.

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References

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