Turbo Segmented Imaging (TSI)

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Introduction

It is desirable in many applications to acquire high-resolution images rapidly, such as for cardiac imaging and functional imaging based on BOLD contrast. Although single-shot ultrafast sequence reduces the scan time, gradient amplitude, slew rate and T_2* limit its achievable resolution. High-resolution imaging thus has to resort to multi-shot segmented acquisitions. The long acquisition time used in the multi-shot methods often leads to motion related image artifacts in the resultant image [1]. Here, we present a new segmentation strategy, termed turbo segmented imaging or TSI, that uses multiple variable flip angle, consecutive excitations to fill the segmented k-space. The new strategy is demonstrated with a segmented reverse spiral (spiral-in) sequence, generating high-resolution images with minimal motion artifacts.

Methods

Fig. 1 illustrates TSI with a 3-segment spiral-in sequence. The 3 segments are acquired consecutively in time, which significantly reduces sensitivity to motion. Instead of using identical RF pulses to excite each segment in the imaged slice, we use variable angle excitation for the segments to ensure equal signal for each segment. The flip angle for segment *n-1* is determined by the relationship $tan(\theta_{n-1}) = sin(\theta_n)$, and θ_n for the last segment being 90°. In the 3-segment case, the flip angles are 35.26°, 45°, and 90°, respectively. In the present implementation, reverse spiral (spiral-in) is used for each segment to obtain images with a desired T_2* weighting and to improve data acquisition efficiency [2]. Spoiling gradients are applied along the slice selection direction to prevent the formation of stimulation echoes. To reduce artifacts arising from imperfections in RF pulses as well as in hardware timing, the acquisition window for each segment is designed to include a few data points before the onset of the spiral gradient (the shaded areas in Fig. 1), and the resulting extra data points are used as reference data to correct for amplitude and phase discrepancies between segments. The data from the three segments are then concatenated and grided onto a Cartesian grid for FFT reconstruction. The new sequence was programmed on a Siemens Magnetom Trio 3T system with a gradient set capable of 40 mT/m with a maximum rise time of 200 µs. The acquisition parameters were, matrix size: 128×128 and 192×192, FOV: 256 mm×256 mm, TR/TE: 2000/30 ms, internal reference scan 500 µs, and 3 segments for a matrix of 128×128 and 5 segments for a matrix of 192×192.

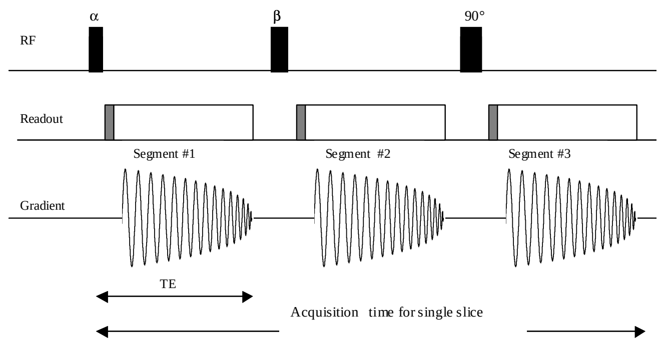

Fig. 1. TSI 3-Segmented sequence

Results and Discussion

Panels (a) and (b) of Fig. 2 show 128×128 images obtained with standard segmentation scheme and TSI, respectively. Fig. 2c shows a 192×192 image acquired with TSI. The total acquisition window for single slice using the TSI at 128×128 and 192×192 are 90 ms and 150 ms respectively, much shorter than the standard multi-shot interleaved spiral sequence at corresponding resolution. The image from the standard multi-shot spiral (a) exhibits significant segmentation artifacts and blurring that may arise from discrepancy between segments (2000 ms). As can be observed, TSI images (b and c) are with much reduced segmentation artifact. Although the 128×128 image acquired with TSI has slightly lower SNR than the same resolution image acquired with standard multi-shot spiral, the reduction in motion artifact makes it a desirable alternative for ultrafast imaging. Some slices from a 15-slice TSI sequence with 128×128 resolution are illustrated in Fig. 3.

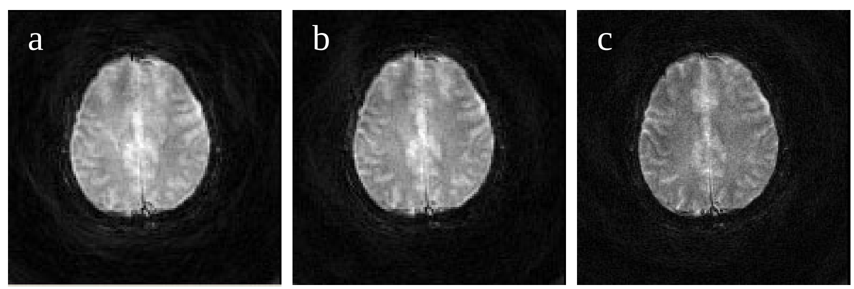

Fig. 2. T_2* weighted images: a. standard multi-shot spiral (128×128, SNR=34); b, c. the TSI sequence (128×128, SNR=32) and (192×192, SNR=26) respectively. The SNR of image c is about 80% of image b.

Conclusions

A new k-space segmentation strategy is developed and demonstrated for segmented spiral imaging. The new acquisition permits rapid k-space coverage of high-resolution images, which can be beneficial in applications where both high resolution and high speed is needed.

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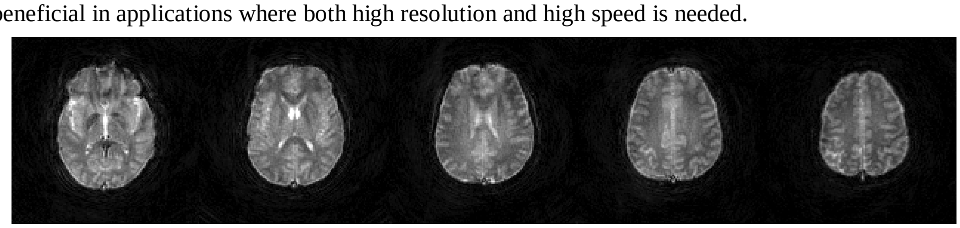

Fig. 3. T_2* weighted image are shown as every 3-slice for Multi-slice experiment using TSI sequence from a healthy volunteer. Matrix size: 128×128, 15 slices with TR /TE 2000/30 ms.

References

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[2] Peter Bornert, et al., Magn Reson Med. 2000; 44:479-484.