Turbo Segmented Spiral Diffusion Tensor Imaging: Acquiring Whole k-data Using Multi-Segments within Single-shot Time Window

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Introduction

Diffusion tensor imaging (DTI), which measures the diffusion anisotropy of water molecules, has become a promising method for mapping neuronal connectivity and detecting abnormalities in the white matter due to neurological and psychiatric disorders. The strong diffusion encoding gradients, however, make DTI not only sensitive to the molecular motion but also to the physiological movement (e.g., cardiac pulses and respirations), gross motion and table vibrations due to the gradients switching. By acquiring the desired k-space data following a single diffusion encoding, single-shot detection schemes, such as echo planar imaging (EPI) and spiral imaging, are less susceptible to motion artifacts and are the most commonly used methods. However, T_2* decay during the long acquisition time limits the achievable spatial resolution and leads to geometrical distortions. Multi-shot methods, based on either EPI or spiral imaging [1-3], have been reported to reduce the susceptibility artifacts and to achieve high spatial resolutions. However, sophisticated navigator echo approaches are normally required to remove inconsistency between interleaves due to motion and/or other variations. Recently, we reported a data acquisition scheme, Turbo Segments Imaging (TSI) [4], that covers the entire k-space using multiple shots within the single shot time window by distributing the signal evenly into different segments and acquire the segments consecutively. In this study, we demonstrate that this acquisition scheme could be utilized in diffusion weighted imaging to reduce acquisition window while avoiding segmentation artifacts without using navigator echoes.

Methods

Fig. 1 illustrates the new imaging sequence for diffusion measurement. A 4-segment spiral TSI sequence was combined with the twice-refocused spin echo (TRSE) sequence, which has the well-demonstrated capability of suppressing eddy currents [5]. The 4 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, variable angle excitations were used for the segments to achieve maximum signal-to-noise ratio. Pairs of gradients (dotted rectangles) were used to form stimulated echo for each segments. To reduce artifacts arising from imperfections in RF pulses as well as in hardware timing, extra data points (40 data points with extra 200 us in this study) before the onset of the spiral gradient were acquired and used as reference data for correcting potential amplitude and phase discrepancies between segments. The data from the 4 segments are then combined and gridded onto a Cartesian grid for FFT reconstruction. The new sequence was implemented 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, FOV: 256 mm×256 mm, slice thickness: 4.0 mm and TR/TE_1/TE_2: 4000/80/10 ms. Seventeen slices were imaged with 32 averages in this study. The FA maps and images were reconstructed offline using a program written in Matlab.

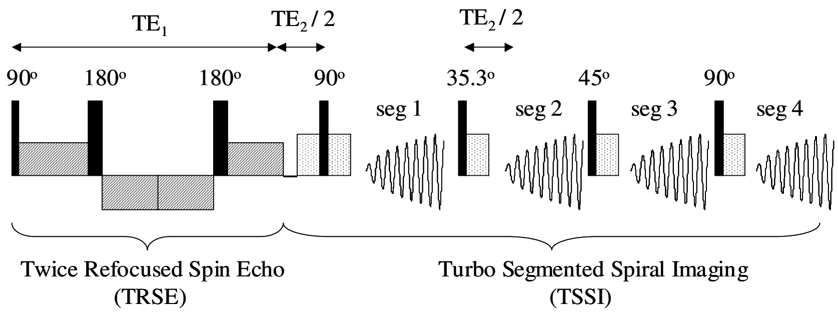

Fig. 1 Sequence diagram for the diffusion tensor imaging with 4 spiral segments. Black Rectangles: RF pulses; dashed rectangles: diffusion gradients; Dotted rectangles: gradients for forming stimulated echo.

Results and Discussion

Panels (a), (b) and (c) of Fig. 2 show 128×128 b-zero images, the corresponding FA maps and color FA maps obtained with the new sequence. The total acquisition window for single slice using the new sequence at 128×128 is 68 ms in duration (17 ms for each read out), which is much shorter than a standard multi-shot interleaved spiral sequence at corresponding resolution. Since all the k-space data were acquired following a single TRSE, inter-segment inconsistency due to motion was negligible and navigator echoes were not required. Segmentation artifacts that are typical for multi-shot methods are absent in the images. Owing to the significantly reduced read out time for each segment, the susceptibility artifacts were also reduced. Extension to higher spatial resolution using more segments is possible and is under investigation.

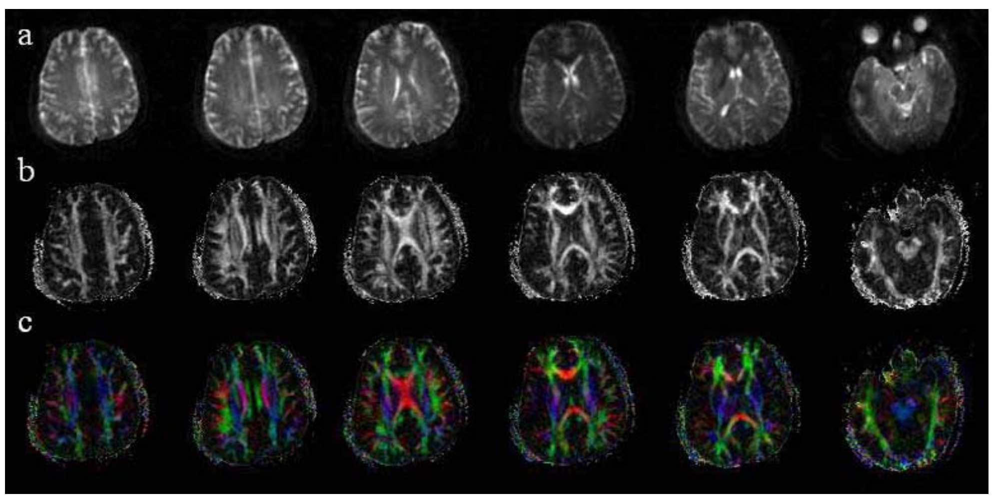

Fig. 2 The b-zero images (a, top), the corresponding FA maps (b, middle) and FA color maps (c, bottom).

Conclusions

A new diffusion sequence based on multiple spiral segments acquired after a single diffusion preparation is developed and demonstrated. Compared to the conventional multi-shot methods, the new method is insensitive to motion and does not require sophisticated navigator echo correction. Experimental data exhibit no significant motion artifacts and reduced susceptibility artifacts.

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References

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