Accelerated Radial Diffusion Spectrum Imaging using a multi-echo stimulated echo diffusion sequence

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Target audience Scientists and clinicians interested in Diffusion Spectrum MRI, its methodological development and its acceleration.

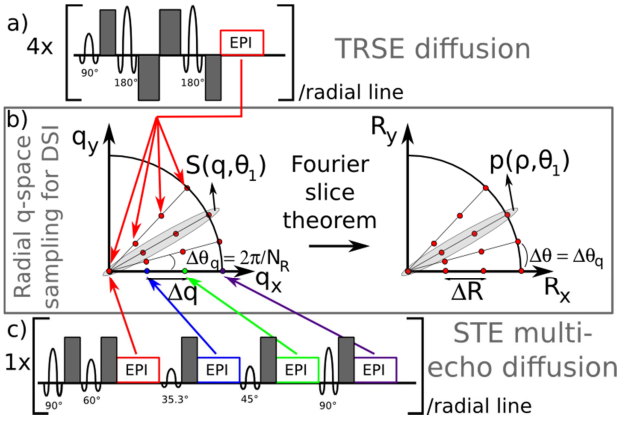

Fig. 1 Radially sampled DSI (b) acquires several q-space samples (e.g. 4) along several radial lines. When using a conventional TRSE diffusion sequence (a), the sequence train has to be repeated several (e.g. 4) times. In contrast, the multi-echo stimulated echo diffusion sequence (c) naturally acquires several (e.g. 4) echoes along the same radial line in q-space in one readout. Once acquired, each radial line in q-space can be transformed to the value of the ODF at the same radial line using the Fourier slice theorem (b).

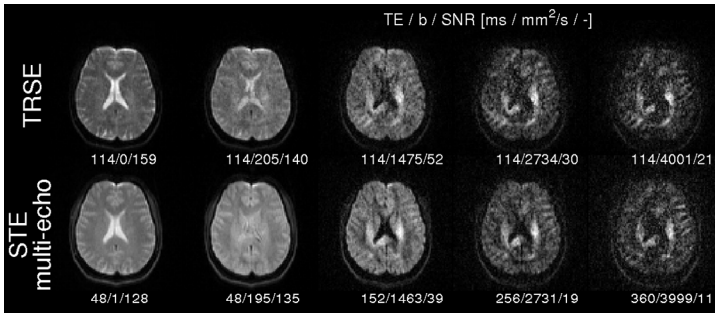

Fig. 2 Raw diffusion weighted images (b_0 and 4 shells) acquired with a TRSE (top row) and a multi-echo stimulated echo (bottom row) diffusion sequence. Below each respective image the echotime, the b-value and the SNR are indicated.

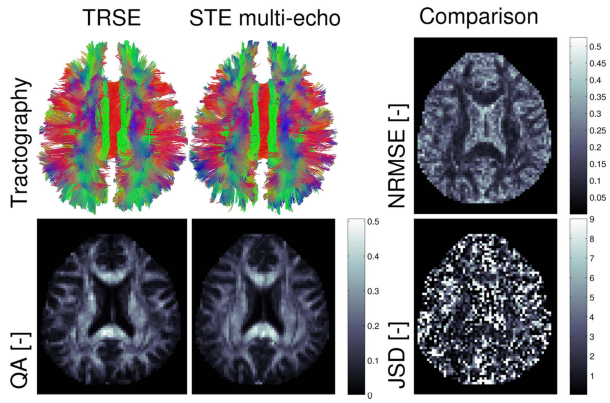

Fig. 3 DSI reconstructions of a human brain volunteer acquired using a TRSE and a multi-echo stimulated echo sequence. Shown are tractography results of the central 10 slices and the quantitative anisotropy (QA) of the prominent fiber orientation. Also included are the normalized RMSE error (NRMSE) and the Jensen-Shannon divergence [11] (JSD) between the ODFs of both datasets.

Purpose To demonstrate the feasibility of accelerating radial q-space sampling for Diffusion Spectrum Imaging (DSI) by acquiring multiple q-space samples in one readout using a multi-echo stimulated echo (STE) sequence.

DSI [1] has been demonstrated to be a robust means to provide non-invasive renditions of the white matter tract architecture in the human brain, including complex distributions of intravoxel fiber orientations [2,3]. This robustness stems from DSI's model-independent estimation of the Orientation Distribution Function (ODF) [1]. DSI achieves its model independence by deriving the ODF from samples of the Fourier Transform of the probability distribution function, which requires a large number of q-space samples to adequately measure the ODF, leading to long acquisition times [4]. One approach to mitigate this, is the use of multi-slice or multiband techniques where several slices are encoded at the same time [5,6]. Another, complementary, approach to improve DSI's efficiency is to acquire several q-space samples per readout train.

The recently proposed Radial q-space sampling for DSI [7,8](Figure 1b) lends itself naturally to the latter approach as it uses the acquisition of multiple q-space samples along a set of radial lines. All, or several, of the samples along the same radial line in q-space can be measured in one readout train of multiple stimulated echoes (Figure 1c), accelerating the acquisition relative to the conventional Twice Refocused Spin Echo (TRSE) diffusion sequence (Figure 1a). In this work, we show the feasibility of accelerating DSI acquisitions using a multi-echo stimulated echo sequence *in vivo* in a clinical 3T scanner.

Methods DSI datasets were acquired using a TRSE (Figure 1a) and a custom-made multi-echo stimulated [9](STE, Figure 1c) diffusion sequence. In both sequences, a recently proposed radial q-space sampling scheme (Figure 1b) was used [7,8]. The radial sampling scheme prescribes several q-space samples along a number of radial lines, in this case 4 samples along each of 59 radial lines evenly distributed on a half sphere (236 samples in total). This has the advantage that every radial line in q-space is directly connected by the Fourier slice Theorem [7] to a value of the radial ODF at the same angular location in the spatial domain. Datasets were acquired of a healthy volunteer (female, 30y/o) on a 3T clinical scanner (Skyra, Siemens, Erlangen) using a 32-channel head coil (b_{max}=4000, TR = 4000, 2.3×2.3×5 mm resolution, 10 slices, multiband acceleration of 2 (SE) [4], SE: TE = 114ms, STE multi-echo: TE = 48,152,256,360ms) in a single scan session (SE: 15:56min, multi-echo STE 4:24min). Reconstruction was performed offline using custom-made software (Matlab, Mathworks) and displayed using Matlab and DSI Studio [10]. ODFs of the respective DSI datasets were compared with each other using the normalized RMSE (NRMSE) and the Jensen-Shannon Divergence (JSD) [11].

Results and Discussion Figure 2 compares raw diffusion weighted images of the SE and the multi-echo STE diffusion sequence. As expected, the SNR of the early echoes in the STE-sequence is lower. However, the overall performance of the approach is still comparable to that of the SE sequence due to the slow signal decay of the STE sequence as the echo time increases for the longer q-space samples. The DSI reconstructions of both methods (Figure 3) return similar tractography results and Quantitative Anisotropy maps. Also the ODF's in the high anisotropy regions are very similar, as illustrated by the NRMSE and JSD maps.

The acceleration of the multi-echo STE DSI is clear when comparing the measurement times, that is, the multi-echo STE DSI acquisition is almost 4 times faster than the SE DSI acquisition (15:56min vs. 4:24min). Another advantage of the multi-echo STE DSI is that the higher diffusion times are expected to lead to increased anisotropy and better fiber tracking [12].

Conclusion An acceleration of radial q-space sampling for DSI is possible using a multiple echo stimulated echo diffusion sequence. Combination of this acceleration with multi-slice or multiband techniques [5,6] can bring DSI acquisition times down to clinically feasible times.

Funding NIH 2R01CA111996-06A1. References [1] Callaghan P., Principles of NMR Microscopy, Oxf. Univ. Press, 1994. [2] Wedeen VJ, et al., Science, 335:1628,2012. [3] Fernandez-Miranda JC, et al., Neurosurg., 71:430, 2012. [4] Setsompop, K, et al., MRM 67:1210-24, 2012. [5] Setsompop K, et al., NeuroImage 63:569, 2012. [6] Blaimer M, et al., MRM 69:974-980, 2013. [7] Boada FE, et al., Proc ISMRM, p3177, 2013. [8] Baete S, et al., ISMRM Diffusion Workshop, p40, 2013. [9] Franconi F, et al., JMRI 7:399-404, 1997. [10] Yeh FC, et al., IEEE TMI 29:1626, 2010. [11] Cohen-Adad, et al., JMRI 33:1194-1208, 2011. [12] Rane S, et al., NMR Biomed 23:459-65, 2010.