Fast, whole brain Radial Diffusion Spectrum Imaging (RDSI) via Simultaneous Multi Slice Excitation

Steven Baete[1,2], Tiejun Zhao[3], and Fernando Emilio Boada[1,2]

[1]*Center for Advanced Imaging Innovation and Research (CAI2R), NYU School of Medicine, New York, NY, United States,* [2]*Center for Biomedical Imaging, Dept. of Radiology, NYU School of Medicine, New York, NY, United States,* [3]*Siemens Healthcare, Siemens Medical Solutions USA, Inc., New York, NY, United States*

Target audience Scientists and clinicians interested in accelerating and acquiring Diffusion Spectrum MRI in a clinically relevant acquisition time.

Purpose To demonstrate the use of multiband acceleration to further speed up acquisition time during multi-stimulated-echo Radial Diffusion Spectrum Imaging (RDSI).

Diffusion Spectrum Imaging (DSI) [1] has become a powerful tool for non-invasive imaging of the brain's white matter architecture, particularly in regions with complex crossing fibers [2,3]. A drawback of DSI is the large number of q-space samples needed to adequately sample the Orientation Distribution Function (ODF), leading to long acquisition times [4]. Several complementary approaches have been employed to mitigate this: simultaneous multi-slice (SMS) or multiband techniques where several slices are encoded at the same time [5,6,7] and undersampled q-space combined with compressed sensing reconstructions [5,8].

Another, complementary, approach to improve DSI's acquisition time efficiency, and accuracy, is facilitated by the recently proposed Radial q-space sampling for DSI (RDS)[9,10] (Fig 1a). In this sampling approach, multiple q-space samples are acquired along each of a number of radial lines. A natural extension is to acquire the q-space samples along the same radial line in one multi-echo stimulated echo readout-train (Fig 1b), accelerating the acquisition relative to a conventional Twice Refocused Spin Echo (TRSE) diffusion sequence [11]. In this work, we combine the acceleration of the multi-echo stimulated echo diffusion sequence with a SMS excitation. This allows for 3T, *in vivo* whole brain, full q-space, four-shell RDSI to be performed in less than 7 minutes.

Methods For RDSI, 4 q-space samples were acquired along each of 59 radial lines evenly distributed on a half sphere (total 236 samples). This sampling strategy has the advantage that each radial line in q-space is directly connected by the Fourier slice Theorem [9] to a value of the radial ODF at the same angular location in the spatial domain ([9], Fig 1a).

A custom-made multi-echo stimulated echo diffusion sequence [11,12](STE, Fig 1b) was expanded to include a Blipped-CAIPI acquisition scheme [4] which introduces an inter-slice image shift between simultaneously excited slices in order to reduce the g-factor penalty. Datasets were obtained from healthy volunteers on a 3T clinical scanner (Skyra, Siemens, Erlangen; 20ch head coil; b_{max}=4000, TR=7900, 40slices, FoV 240mm, 3×3×3mm, TE = 48,152,256,360ms, 2x in slice GRAPPA, PF 6/8, no SMS, SMS2 and SM3). Imaging times were 17:23 without acceleration and 9:13, 6:47 with SMS 2 and 3; respectively (a fully sampled TRSE approach would be 28:30). The SMS-aliased slices were separated offline using the slice-GRAPPA algorithm [4] followed by conventional GRAPPA to generate the missing k-space lines for the inslice undersampling. Images were corrected for susceptibility, eddy currents and subject motion using *eddy* from the FSL Library [13]. DSI reconstructions, incorporating variable sample density correction, were performed offline using custom-made software (Matlab, Mathworks) and displayed using Matlab and DSI Studio [14]. The resulting DSI datasets were then compared using the Normalized RMSE (NRMSE) and the Jensen-Shannon Divergence (JSD) [15] of the ODFs relative to the non-accelerated dataset.

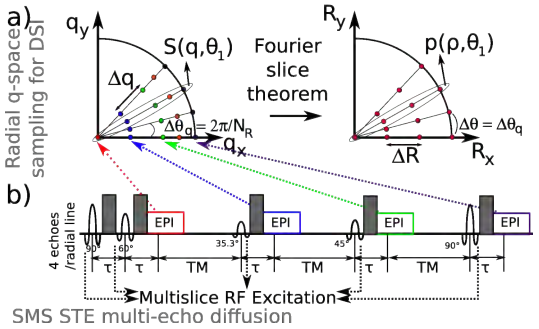

Fig. 1 Radially sampled q-space for DSI requires acquisition of multiple samples (e.g 4) along a set of radial lines (a). Acceleration is possible by measuring all samples along a line at once using a multi-echo stimulated echo diffusion sequence (b).

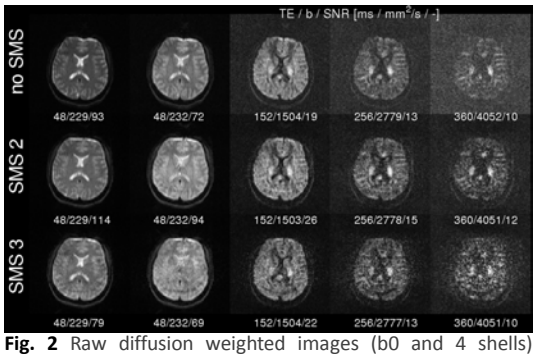

Fig. 2 Raw diffusion weighted images (b0 and 4 shells) acquired without (top) and with simultaneous multislice acceleration (middle SMS2, bottom SMS3). TE/b-value/SNR are indicated below each image.

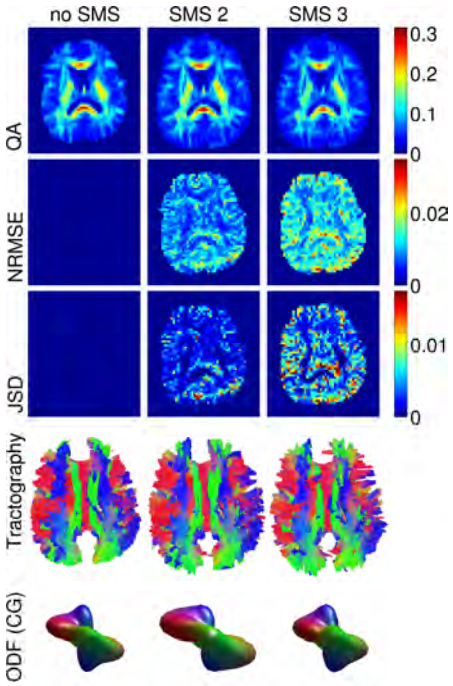

Fig. 3 Radial DSI reconstructions acquired with a multi-echo stimulated echo diffusion sequence without and with 2 and 3x SMS acceleration. Shown are the Quantitative Anisotropy (QA)[16], the NRSME and JSD of the ODF relative to the non-accelerated measurement, tractography (center 10 slices) and a single ODF from the Cingulum.

Results and Discussion The reconstructed raw diffusion weighted images in Figure 2 illustrate the performance of the slice-GRAPPA reconstruction algorithm. While the SNR at different SMS factors remains comparable, small reconstruction artifacts can be seen in the images (edge artifacts in the SMS3-images, for example). These artifacts could be reduced by using a higher number of coil channels (e.g. 32), by incorporating variable-rate selective excitation pulses (VERSE)[17] and by using the modified even/odd grappa kernel [6] or a generalized SENSE-style reconstruction [18]. Reconstructions of the DSI datasets return similar Quantitative Anisotropy (QA) maps and tractography results. In addition, the NRMSE and JSD measures comparing the ODFs acquired with SMS acceleration with the non-accelerated datasets are small. These measures increase as expected with the SMS acceleration factor. In studying the acquisition times, it can be seen that the speedup of the multi-band acquisition (SMS3: 6:47) is additive to the speedup of the multi-echo stimulated echo sequence (17:23) relative to a TRSE sequence (28:30).

Conclusion RDSI can be sufficiently accelerated to acquire a whole in vivo brain dataset with fully sampled q-space in under 7 mins when combining the acceleration of a multi-echo stimulated echo sequence with simultaneous multislice acceleration. This brings DSI acquisitions in the realm of clinically feasible acquisition times on conventional clinical 3T scanners.

Funding: NIH 1NS082436-01A1, NIH 2R01CA111996-06A1 and NIH R01 MH088370. References [1] Callaghan P., Principles of NMR Microscopy, Oxf. Univ. Press, 1993. [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., Proc ISMRM, p693, 2012. [6] Setsompop K, et al., NeuroImage 63:569, 2012. [7] Blaimer M, et al., MRM 69:974-980, 2013. [8] Menzel, et al., MRM 66:1226-33, 2011. [9] Boada FE, et al., Proc ISMRM, p3177, 2013. [10] Baete S, et al., Proc ISMRM, p663, 2014. [11] Baete S, et al., Proc ISMRM, p88, 2014. [12] Franconi F, et al., JMRI 7:399-404, 1997. [13] Jenkinson, et al., NeuroImage 62:782-90, 2012. [14] Yeh FC, et al., IEEE TMI 29:1626, 2010. [15] Cohen-Adad, et al., JMRI 33:1194-1208, 2011. [16] Yeh FC, et al., IEEE TMI 54:1377-1386, 2005. [17] Conolly S, et al., JMR 78:440-58, 1988. [18] Zahneisen B, et al., MRM 71:2071-81, 2014.