Large-FOV Tractography of the Brain and Spinal Cord with Reduced Scan Time: A Study using Diffusion-Weighted, Readout-Segmented EPI and Simultaneous Multi-Slice Acceleration

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Target audience: Neuroscientists, neurosurgeons, neurologists, radiologists and sequence programmers

Purpose: Readout-segmented Echo Planar Imaging (rs-EPI) with 2D navigation[1] is an established clinical technique for acquiring diffusion-weighted (DW) images with a low level of distortion and T2*-related blurring. The method can be used to acquire high-quality DW data from the whole brain and cervical spine simultaneously with a large field of view (FOV)[2,3]. However, one disadvantage of rs-EPI compared with single-shot EPI (ss-EPI) is a longer scan time, which increases with the number of readout segments. The blipped-CAIPIRINHA[4] approach to simultaneous multi-slice (SMS) acceleration[5] has been used to substantially reduce scan time in ss-EPI studies without compromising image quality and the technique has also been successfully extended to rs-EPI[6-8] in the brain. In this study, we demonstrate how the blipped-CAIPIRINHA SMS technique can be used with rs-EPI to provide a unique method for performing rapid tractography studies of the brain and spinal cord with low distortion and a large anatomical coverage.

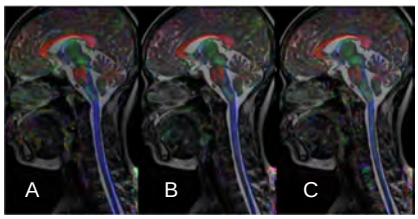

Fig 1: Comparison of color FA maps for Non SMS(A), SMS2(B) and SMS3(C). All images are overlaid on the anatomical image.

Methods: The blipped-CAIPIRINHA SMS scheme[4] and corresponding inline split slice GRAPPA reconstruction[9] were used to generate a non-product version of a commercial rs-EPI sequence (RESOLVE, Siemens Healthcare). To optimize the acquisition and reconstruction workflow, reference data for Nyquist ghost phase correction were obtained from a SMS acquisition of the central readout segment similar to that used for SMS-accelerated ss-EPI[10]. Acquisitions: The study was performed on a commercial 3T scanner (MAGNETOM Spectra, Siemens Healthcare) equipped with a 20-channel head and a 24-channel spine coil. DW images from a healthy volunteer were acquired with conventional and two SMS-accelerated rs-EPI protocols (SMS2 and SMS3 with slice acceleration factors of 2 and 3 respectively). Imaging parameters were as follows: FOV = 300x226 mm^2, matrix size = 122x92, 54 slices with 2.5 mm isotropic resolution without slice gap, segments = 5, TE = 82 ms, in-plane GRAPPA factor = 2, b = 800 s/mm^2, diffusion-weighting directions = 30. Three b=0 images were acquired interspersed with the DW images. All images were acquired with cardiac gating to minimize cardiac-pulsation-related artifacts. The conventional scan had a TR 8970 ms and a total scan time of 25:08 min; the SMS2 scan had a TR 4490 ms and a total scan time of 12:58 min; the SMS3 scan had a TR 2990 ms and a total scan time of 8:48 min. In both SMS cases, a phase-encoding shift factor of FOV/2 was used to improve the g-factor performance[11]. Postprocessing: Images were corrected for motion and eddy-current induced distortion and then registered to 1 mm isotropic anatomical images (SPACE). Tractography was performed using Diffusion Toolkit and displayed with TrackVis[12] (http://www.trackvis.org).

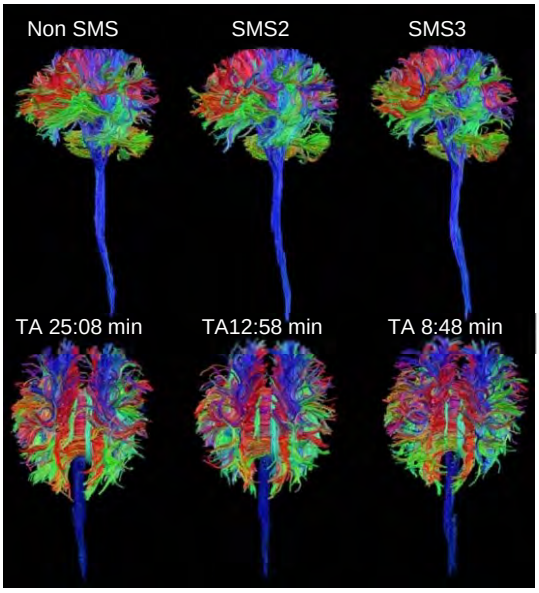

Fig. 2: Comparison of tractography results from conventional and SMS-accelerated rs-EPI. From left to right, 3D tracktography results from conventional, SMS2 and SMS3 rs-EPI. Even with shorter TR(~3s), the images acquired by SMS3 rs-EPI (last column) have comparable tracts as those from convertional rs-EPI, but ~65% acquisition time reduction.

Results: A comparison between apparent diffusion coefficient (ADC) and fractional anisotropy (FA) values in a healthy volunteer for different anatomical regions is shown in Table 1. All values are measured in the same region of interest in each case and show equivalent quantitative diffusion information. Fig. 1 shows color FA maps for the three scans in a healthy volunteer. In all FA images, the anatomy is well depicted and the image quality is comparable. In the SMS-accelerated cases, reasonable scan time is achieved for whole brain and spinal cord coverage. For example, in the SMS3 scan the total acquisition time is reduced to 8:48 min, compared with 25:08 min in the conventional scan. The low level of susceptibility distortions in the images makes it possible to explore white-matter connections from cortical areas down to the spinal cord with high fidelity without the need for further distortion correction[2]. The tractography results are shown in Fig. 2, with different viewing angles. In all cases fibers could be tracked with high accuracy within and between the brain, brainstem and cervical spinal cord.

	Brain		Brainstem		Spinal cord	
	ADC(x10^{-3} mm^2/s)	FA	ADC(x10^{-3} mm^2/s)	FA	ADC(x10^{-3} mm^2/s)	FA
Non SMS	0.732±0.057	0.600±0.095	0.777±0.142	0.548±0.139	1.064±0.111	0.603±0.075
SMS2	0.717±0.038	0.628±0.081	0.743±0.120	0.596±0.183	1.142±0.131	0.622±0.105
SMS3	0.723±0.038	0.585±0.087	0.809±0.118	0.527±0.148	1.081±0.179	0.568±0.092

Table.1 ADC and FA comparison in a healthy volunteer. Values are reported as mean ± std.

Conclusion: This study has shown that SMS-accelerated rs-EPI can perform diffusion imaging of the whole brain and cervical spinal cord with a low level of susceptibility-based distortion, whilst preserving data quality for tractography studies. The technique achieves a substantial reduction in scan time compared to previous studies, which promises to increase the range of neuro-scientific and clinical applications.

References: **1.** Porter *MRM* 2009. **2.** Julien Cohen-Adad *MAGNETOM FLASH* 2012. **3.** Keil *ISMRM* 2013. **4.** Setsompop *MRM* 2012. **5.** Larkman JMRI 2001. **6.** Frost *ISMRM* 2012. **7.** Holdsworth *ISMRM* 2013. **8.** Frost *MRM* 2014. **9.** Cauley *MRM* 2014. **10.** Setsompop *NeuroImage* 2012. **11**. Breuer MRM 2005. **12.** Wang. ISMRM 2007.