Accelerated Diffusional Kurtosis Imaging using Simultaneous Multi-slice Echo Planar Imaging

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Introduction: Diffusional kurtosis imaging (DKI) extends diffusion tensor imaging (DTI) by quantifying the non-Gaussian behavior of water diffusion [1]. In addition to conventional DTI parameters, DKI generates metrics related to the kurtosis of the water diffusion probability density function, including the mean, axial and radial kurtoses. Established DKI acquisition protocols typically use multi-slice 2D echo planar imaging (EPI) with multiple b-values (≥3) and typically 30 gradient directions, which requires 7 to 15 minutes for full brain coverage [2]. A technique with slice acceleration that can either decrease the scan time or accumulate more data for a given scan time is desired. Recently a slice-acceleration method which excites multiple slices acquired simultaneously with the blipped CAIPIRINHA technique was introduced [3]; the slice GRAPPA method was used to separate the simultaneously excited slices. In this study, the combination of DKI and the aforementioned slice acceleration technique was performed and initial assessments and comparisons were reported.

Purpose: To compare the performance of simultaneous multi-slice acquisition with conventional multi-slice EPI acquisition in DKI.

Materials and Methods: In this study, SE-EPI diffusion-weighted imaging was performed using either conventional single-slice imaging or slice-accelerated (2X) simultaneous multi-slice acquisition. Images were acquired from a healthy subject, after obtaining informed consent, using a 3T whole-body scanner (Skyra, Siemens, Germany) and the commercially available 20-channel head/neck array coil with only the 16 head elements activated. Two experiments were performed to compare the slice-accelerated blipped-CAIPI acquisitions to their equivalent conventional acquisitions with no slice-acceleration. The first experiment utilized a slice acceleration factor (Rsl) =1 and in-plane phase encoding acceleration (Rpe) =1 as the baseline. Acquisition parameters were: resolution 2.7x2.7x2.7 mm^3; FOV 220x220x113 mm^3, bandwidth 1905 Hz/pixel, b-values of 0, 1000 and 2000 s/mm^2, 30 directions, 42 slices, TE 110 ms, TR 7900 ms. The second experiment focused on SNR and diffusion metrics in DKI acquisition with Rpe=1, Rsl=2 and TR=5900 ms. Other parameters similar to the first experiment. The slice-GRAPPA algorithm was used to unalias the multiple slices, in which a GRAPPA-like kernel was fit to each slice of a pre-scan calibration dataset acquired one slice at a time and then applied to the aliased data to estimate the k-space points of each individual imaging slice. Mean kurtosis (MK) and mean diffusivity (MD) maps were generated using in house software [2].

Results: For the conventional (Rsl=1, Rpe=1) acquisition, the total acquisition time was Tacq=8.03 minutes and the slice accelerated acquisition (Rsl=2, Rpe=1) resulted in Tacq=6 minutes. Figure 1 shows the b = 0 images for (A) baseline (SL1) and (B) a slice acceleration factor of 2 (SL2) acquisitions with the same brightness and contrast levels. There were no apparent differences between these images. Figure 2 shows the MK (A-B) and MD (C-D) maps for SL1 and SL2 acquisitions, respectively. Parameter maps were calculated after applying Gaussian smoothing with a full-width at half maximum of 3.375 mm. Figure 3 shows regional averages for the MK and MD for SL1 and SL2 acquisitions in white and gray matter. White matter voxels were defined as those with a fractional anisotropy greater than 0.3, cerebrospinal fluid (CSF) regions were defined as voxels with MD greater than 1.5 $\mu m^2/ms$, and gray matter regions were defined as brain tissue other than the white matter and CSF regions.

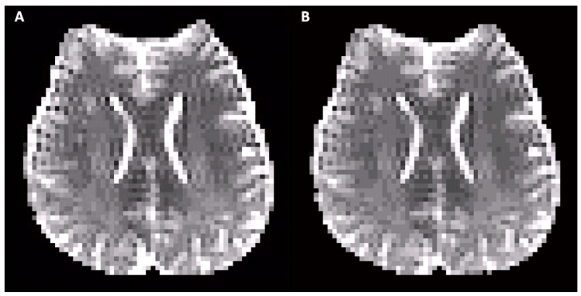

Figure 1: b = 0 images for (A) SL1 and (B) SL2 acquisitions. Results are shown with same brightness and contrast levels.

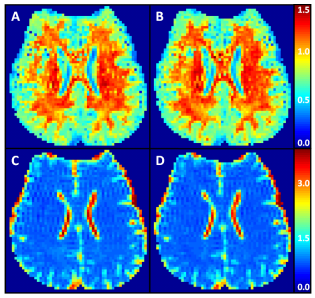

Figure 2: MK (A-B) and MD (C-D) maps for SL1 (left) and SL2 (right) acquisitions. The calibration bar for the diffusivity is in units of $\mu m^2/ms$.

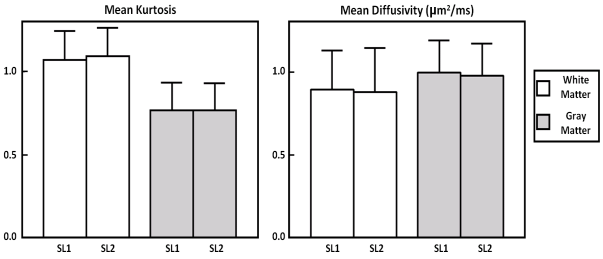

Figure 3: Regional averages (+/- s.d.) for MK and MD for SL1 and SL2 acquisitions in white and gray matter.

Discussion and Conclusions: In this study, performance of the blipped-CAIPI method in 2x simultaneous multi-slice DKI was compared to conventional multi-slice 2D EPI acquisition. Through these quantitative and qualitative assessments, we show that data acquisition times for DKI can be reduced substantially using the simultaneous multi-slice approach without loss of data integrity, thereby providing a significant gain in sensitivity per unit time. Further evaluation of this approach is currently in progress, including assessment of the feasibility and clinical efficacy in a patient cohort and higher acceleration factors using larger element coil arrays.

References: [1] Jensen JH & Helpern JA, NMR Biomed. 2010; 23(7):698-710. [2] Tabesh A et. al., MRM 2011; 65:823–836. [3] Setsompop K. et al. MRM 2012; 67(5):1210–24.