Diffusion Weighted Imaging Using Multi-shot Spiral with a Simultaneous Multi-slice Excitation

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INTRODUCTION: There has been an increase in the use of 3D k-space trajectories in diffusion imaging due to the benefit of increased SNR efficiency. In order to do 3D k-space encoding a 3D volume must be excited. Two approaches have been used to excite a 3D volume. The multi-slab approach excites several adjacent slices at once while the simultaneous multi-slice (SMS) approach excites slices that are distributed throughout the imaging volume. These 3D excitation schemes allow for higher SNR efficiency [1,2], however taking advantage of the higher SNR to get better resolution requires using multiple shots due to distortions from field inhomogeneity with long data readouts. Several groups have demonstrated multi-shot approaches for doing multi-slab DWI [1-3], however the multi-shot SMS has only been done using readout segmented EPI [4]. In this work, a time efficient DWI pulse sequence that is able to use multi-shot spiral readouts and correct for motion induced phase errors is demonstrated.

METHODS: To achieve a multi-shot DWI acquisition the pulse sequence in figure 1 was used. A standard PGSE encoding scheme is used for diffusion weighting. The RF pulses to achieve multi-band excitation followed the technique by Wong [5] to produce low power SMS pulses. In this work 4 slices were excited simultaneously, but the scheme could be used to excite more slices. To correct for motion induced phase errors a single shot low resolution 3D navigator image was acquired. A 3D navigator is required as the motion induced phase errors vary among the slices within an excitation, unlike in the multi-slab approach were variation within the slab in the slice direction can often be considered negligible. The navigator used had a matrix size of 24x24x4 and used a blipped spiral-in trajectory [6]. For imaging data, a stack of spirals trajectory was used with a single interleave of the spiral trajectory at one kz plane acquired at each excitation. A matrix size of 120x120x4 was used for imaging data with 4 kz planes being acquired and data being under sampled by a factor of 2 in-plane. 60 2mm thick slices were acquired with a TE/TR of 88/2055 ms with 30 diffusion directions and 2 images without diffusion weighing. Data were collected using a Siemens 3T Trio on a 32 channel head coil. The images were reconstructed using custom routines in MATLAB and used NUFFT libraries for reconstruction [7]. Motion correction was performed by reconstructing the navigator images and using the phase of the navigators to model the spatially varying phase among the shots [8].

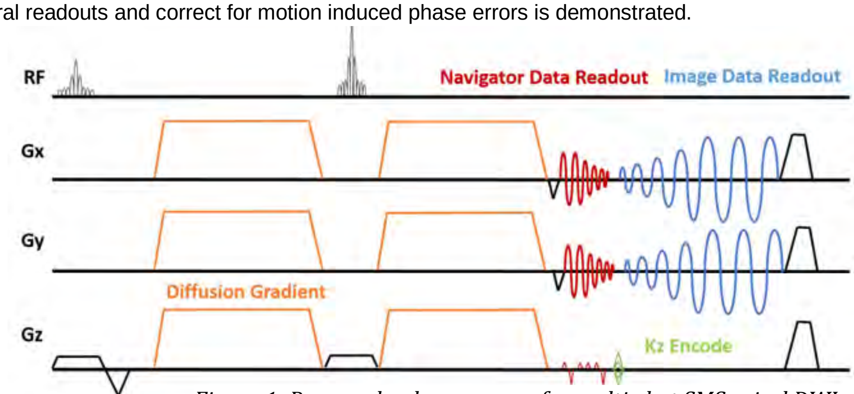

Figure 1: Proposed pulse sequence for multi-shot SMS spiral DWI

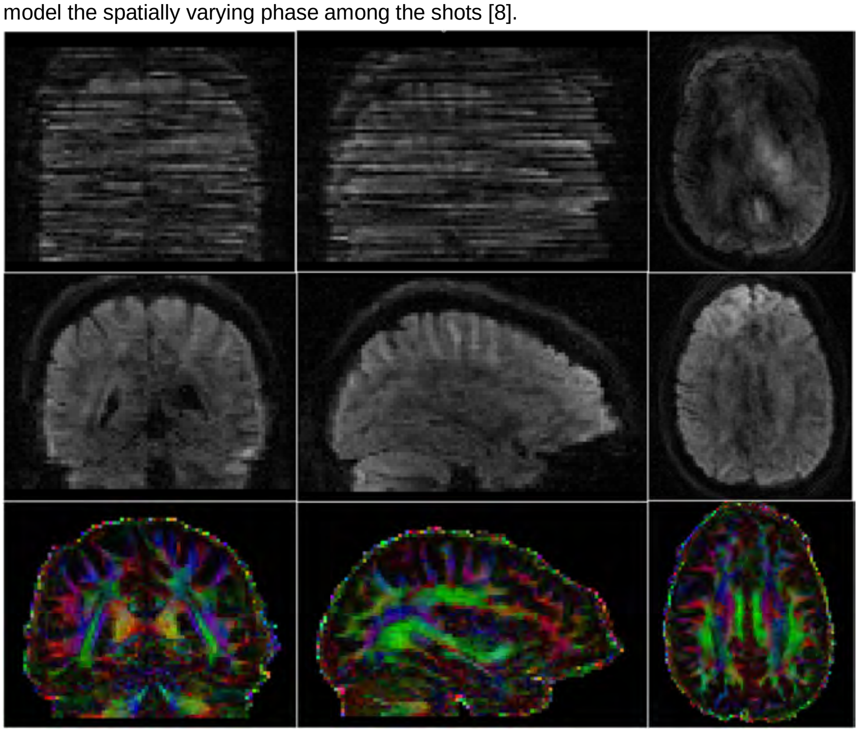

Figure 2: Multi-shot spiral SMS imaging results. Top row shows a diffusion weighted image without any motion correction. Middle row shows a diffusion weighted imaging with the described motion correction. The bottom row shows a calculated color FA image. The columns are the coronal, sagittal, and axial views of the image respectively.

RESULTS and DISCUSSION: Figure 2 presents imaging results using the proposed technique. The navigator provided sufficient information to accurately compensate for the motion induced phase errors and as can be seen by comparing the top and middle rows of figure 2. The bottom row of figure 2 shows that the technique was able to work on a multi-direction data set and gives high quality results for estimation of DTI parameters. The ability to combine spiral readouts in both navigator and imaging data in multi-shot DWI has the potential to provide several improvements to the area of diffusion imaging. The short blipped spiral-in navigator is a time efficient way to collect navigator data as no additional refocusing pulse is needed for acquiring the navigator, as is often done in navigated multi-shot DWI.

CONCLUSIONS: The proposed sequence and reconstruction procedure provide a method that allows for the use of spiral trajectories in multi-shot SMS DWI. The ability to use an SMS excitation over the multi-slab approach will enable reduction factors in the slice encoding direction, allowing for a reduction of scan time or the ability to acquire additional images. The blipped spiral-in trajectory was able to accurately capture the motion induced phase errors and when combined with a spiral out readout provide an efficient way to collect data that does not require addition refocusing pulses to collect navigator data.

REFERENCES: [1] Van et al, ISMRM 2010, p. 1618 [2] Engström et al., MRM (2013) doi: 10.1002/mrm.24594 [3] Frost et al, ISMRM 2013, p. 3176 [4] Frost et al, MRM (2014) doi 10.1002/mrm.25391 [5] Wong ISMRM 2012, p. 2209 [6] Stenger MRM (2013), doi 10.1002/mrm.24875 [7] Sutton et al, IEEE Transactions (2003) doi 10.1109/TMI.2002.808360 [8] Liu et al, MRM (2005) doi 10.1002/mrm.20706