3D Self-Navigated Interleaved Spiral (3D-SNAILS) for DWI

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INTRODUCTION 3D diffusion imaging offers some very desirable features such as isotropic resolution and higher signal-to-noise ratio. One of the major challenges for 3D diffusion imaging is the motion correction problem since a high resolution DWI/DTI acquisition inevitably requires multiple shots and long acquisition time. Self-Navigated InterLeaved Spiral (SNAILS) is an effective 2D diffusion imaging method in which motion-induced phase errors can be estimated and corrected by using variable-density (VD) spiral trajectories. Currently, there is a lack of effective 3D self-navigated DWI methods. Here, we present a novel 3D-SNAILS approach that is capable of estimating and correcting 3D linear and non-linear phase errors. Our preliminary results show that 3D SNAILS can provide effective 3D phase navigations and high quality 3D DWI volume scans.

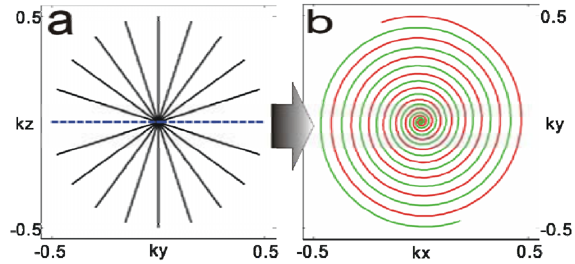

Fig 1 – Radialized Spirals. (a) k-space is fully sampled by a set of radial planes rotating along kx; (b) Overview of the horizontal plane. It is sampled by interleaved spirals

METHODS A feasible 3D self-navigated interleaved trajectory design should meet the following requirements: 1) a small region near the center of the k-space must be fully sampled as a 3D navigator for each interleaf; 2) Nyquist sampling criteria must be satisfied to avoid aliasing. In addition, high sampling efficiency is desired whereas the gradient and slew-rate constraints must not be violated.

A straightforward 3D extension of 2D VD-spiral is the radialized VD-spiral, as shown in Fig 1. The whole 3D k-space is fully sampled by a set of radial 2D planes with each one sampled by interleaved VD-spirals. To achieve 3D navigation, we modify the beginning part of each interleaf by applying a short continuous and oscillating z-gradient along the perpendicular direction (kz), as shown in Fig 2c. This zigzaged or EPI-fashioned spiral segment will fully sample a small cylindrical volume at k-space origin. As a result, the overall kxy trajectory is still a variable-density spiral with its beginning part very slowly sampled and remaining part regularly sampled (slew-rate limited). To further reduce the length of the navigator, we can also replace the central part of each VD-spiral by an Archimedean one, as shown in Fig 2b.

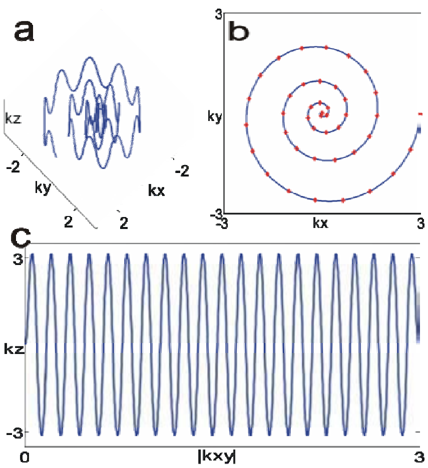

Fig 2 – EPIed Spiral as a navigator. (a) 3D look. (b) kxy is just a slowly sampled spiral. In-plane samples are marked out. (c) kz of the navigator part is a continuous EPI.

A two-stage gridding approach is used for our reconstruction to avoid the massive 3D weighting density computation. First, in-plane samples are gridded to its corresponding “radial k-space Cartesian plane”. Afterwards, each radial plane is gridded into the true 3D k-space Cartesian grids. Analogous to 2D SNAILS, the navigator of each interleaf is used to estimate the phase errors. Finally, the motion corrected reconstruction can be done by either applying direct phase subtractions or conjugate-gradient iterations.

A 3D-SNAILS trajectory was designed for a matrix size of 128x128x128 and a FOV of 24cm. There were 1200 interleaves with each one containing 4214 samples. This trajectory was tested on simulated phantoms and DWI data with intended phase errors.

RESULTS Fig 3a and 3c show slices of reconstructed volumes after applying phase estimation and subtraction. For comparison, the corresponding slices reconstructed by using directly 3D griddings are shown to the right. The motion induced phase corruptions were significantly reduced by utilizing our 3D navigators. Similar to 2D-SNAILS, the image quality can be further improved by doing more conjugate-gradient iterations.

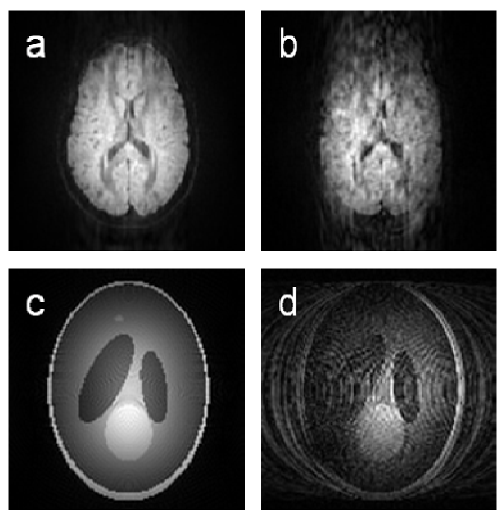

Fig 3 – 3D reconstruction results of simulated DWI data by using 3D-SNAILS. (a) and (c) were reconstructed with phase error estimation and subtraction. (b) and (d) show the corresponding slices reconstructed by direct 3D griddings.

DISCUSSION AND CONCLUSION A new 3D Self-Navigated Interleaved Spiral (3D-SNAILS) method is presented and tested for 3D diffusion imaging. The trajectory is easy to design and the reconstruction can be easily accomplished by 2D griddings. High quality DWI volumes can be obtained through phase error estimation and correction. 3D-SNAILS will be an effective technique for studying tractography since it images diffusion weighted volumes with isotropic resolution and high SNR. In most applications, a reduction of scan time can be achieved via undersampling the outer k-space. According to our results, the total number of interleaves can be reduced by up to 50% without introducing non-tolerable aliasing.

REFERENCES 1. Liu C., et al., Magn Reson Med, 52, 1388-1396, 2004; 2. Anderson AW., et.al., Magn Reson Med, 32, 379-87.

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