3D Multi-Band Diffusion MRI

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Target Audience: Scientists and clinicians in the field of diffusion MRI

Purpose:

After two decades of significant growth, diffusion MRI (dMRI) is now one of the most useful techniques for investigating brain microstructure. Recent advances in high-resolution dMRI have also allowed researchers to study exquisite details of the brain, for example, the microstructures of the cortical gray matter in vivo[1,2]. However, most high-resolution techniques, to date, are limited by the low signal-to-noise ratio (SNR) and also the long acquisition time. In this report, we address both issues by developing a sequence for acquiring 3D dMRI with multi-band imaging. Specifically, a combination of 3D Fourier encoding with the blipped-CAIPI[3] multi-band imaging technique is presented to acquire dMRI images with improved SNR and shortened acquisition time. It is anticipated that this advance will remove the final technical obstacle for a wide-adoption of high-resolution dMRI.

Methods:

In our proof-of-concept implementation, we acquired three 10 mm thick 3D slabs, each comprised of ten adjacent slices, using a multi-band 3D EPI sequence. Using a repetition time (TR) of 4 sec, an echo time (TE) of 59 msec and partial-Fourier *k*-space coverage (62% of k_y), dMRI data was acquired with a maximum b-factor of 800 sec/mm^2. A cosine modulated RF pulse was used to simultaneously excite three slabs at once, and slice-encoding blips were performed together with the phase encoding blips to apply the blipped-CAIPI FOV shifting in the phase encoding direction. After acquiring 3D multi-band *k*-space data with a 32 channel head coil (Nova Medical Massachusetts), each of the ten k_z-encoded planes of *k*-space were individually reconstructed with an inverse Fourier Transform (iFT) and un-aliased with the SENSE[4] algorithm prior to a final iFT applied across the slices within each slab. An additional navigator image was acquired after the acquisition of each k_z-encoded plane of *k*-space to estimate the phase variations over the slices within each slab. These variations are removed after the SENSE reconstruction, prior to the final iFT along the slice dimension.

Results & Discussion:

Four representative slices in the center of a slab, acquired with a 3D multi-band EPI sequence, are presented in Figs. 1a and 1b to illustrate the T2 weighted and diffusion weighted images respectively. In the upper row of Fig. 1 are the aliased images (averaged over coils and presented with an iFT applied in the slice dimension) that were acquired with the blipped-CAIPI technique. After separating the slices from the three simultaneously excited bands using the SENSE algorithm, the un-aliased slices from each of the three slabs are labeled as bands 1, 2, and 3, and shown below the respective aliased image. The geometric distortion noted in the frontal lobe of the brain in Fig. 1 is expected when using single-shot EPI in the presence of frontal magnetic field inhomogeneity, and will be mitigated by extending our current implementation to include multi-shot EPI acquisition (e.g. multiplexed sensitivity encoding, or MUSE[5]) to achieve high spatial resolution at both high SNR and high temporal resolution. This effort is currently underway.

Conclusion:

A technique for acquiring and reconstructing multi-band 3D dMRI has been implemented and demonstrated. With the use of simultaneous slice excitation, we were able to greatly shorten data acquisition times while maintaining the same high SNR of 3D MRI. In our continued work of integrating the high-resolution MUSE acquisition technique, we expect that whole-brain dMRI data at sub-millimeter (0.9 mm) isotropic spatial resolution can be acquired in less than 2.5 minutes using multi-band imaging and shortened TRs. An imaging protocol of this kind will facilitate a wide adoption of high-resolution dMRI and diffusion tensor imaging (DTI), which have shown great promise in delineating complex brain microstructure and exquisite connectivity patterns in healthy and diseased brains[6].

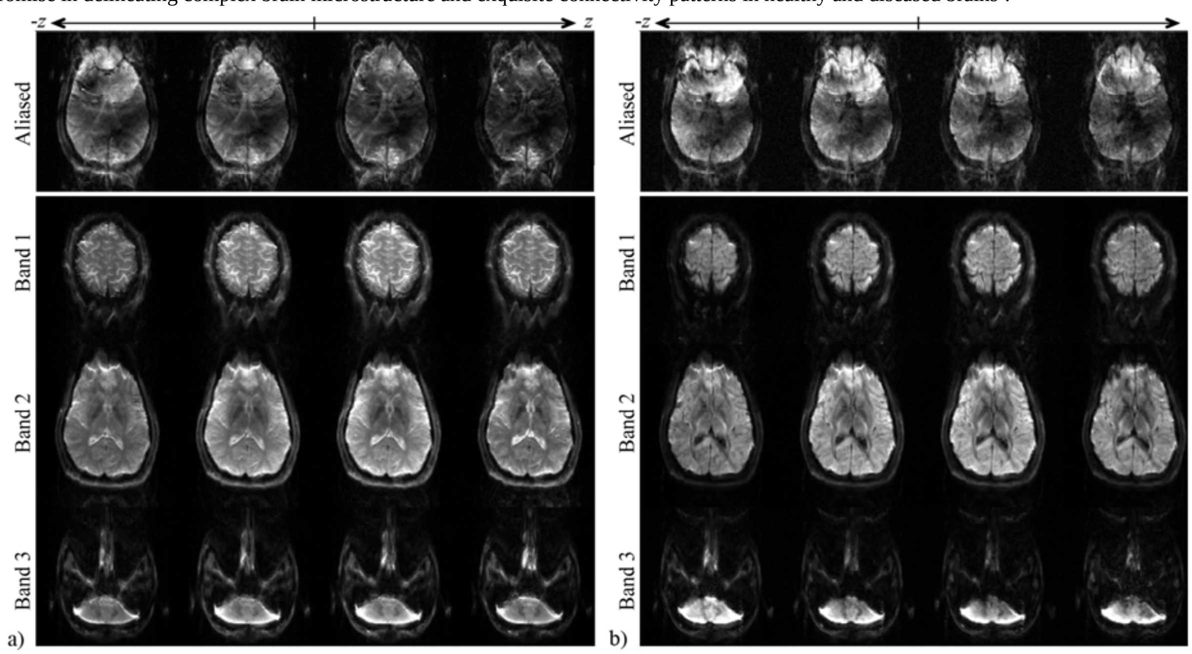

Fig 1: The center four aliased and un-aliased slices in a 3D slab of a) T_2 and b) DW images simultaneously acquired with three bands.

References:

[1] McNab et al., Neuroimage 69:87-100, 2013. [2] Truong et al., PLoS ONE 9(3): e91424, 2014. [3] Setsompop et al., Magn. Reson. Med. 67:1210-1224, 2012. [4] Pruessmann et al., Magn. Reson. Med. 42:952-962, 1999. [5] Chen et al., Neuroimage 72:41-47, 2013. [6] Song et al., Brain Connectivity (Epub ahead of print), 2014.