Considerations in P-Space Susceptibility Tensor Imaging: K-Space Truncation Effect, T2* Dependence, and 3T/7T Comparison

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Target Audience Researchers who are interested in magnetic susceptibility anisotropy.

Purpose The phase of MRI signals of the white matter are found to be dependent on the orientation of the neuronal fibers with respect to the B_0 field[1]. Methods that quantitatively measure the magnetic susceptibility anisotropy (MSA) using a number of phase images acquired by rotating the subject orientation were previously presented[2, 3]. More recently, the multi-pole based (p-space) susceptibility tensor imaging (STI)[4] method that only requires single gradient echo MR scan was developed and was successful to produce a tensor image of mouse brain at 7T, which was strikingly correspondence to diffusion tensor image (DTI). However, although the p-space theory seems very promising, the sensitivity and practicality of the method need to be further explored, especially considering that the STI map of 3T human brain in the paper[4] looked different from typical DTI images. In this study, we explored (1) k-space truncation effect when shifting k-space data, (2) $T2^*$ dependence, and (3) field strength dependence of the p-space STI in *in vivo* human brain.

Methods Clinical 3T 750 and 7T 950 GE MR scanners were used to acquire *in vivo* whole brain images. GE 8-ch Rx and NOVA 2-ch Tx/32-ch Rx coil were used for 3T and 7T scans, respectively. The brain data were acquired using multi-echo SPGR sequence (echo time = 2.8ms, echo spacing = 4ms, flip-angle = 7^o, matrix size = 192^3, voxel size = $1mm^3$, 5 echoes, coronal plane) from a healthy adult volunteer. To assess the k-space truncation effect in calculation of P-matrix, k-space data was sampled up to $k_{max}/2$ and, the resulting dipolar frequency P-matrix (standard deviation of k-space-shifted and linear phase-corrected phase maps) was compared with P-matrix calculated from full k-space shift, k_{max}-15 (Fig.1A). The truncation-free P-matrix has a half of spatial resolution to eliminate the truncation effect. Each echo was used for calculating individual P-matrix as well as their weighted averages along X-, Y-, and Z-directions to investigate the TE-dependence of the susceptibility anisotropy. Differences between P-matrices acquired along the three principle-axes were normalized by the sum of the three P-matrices to compare the performance of the p-space MSA at 3T and 7T.

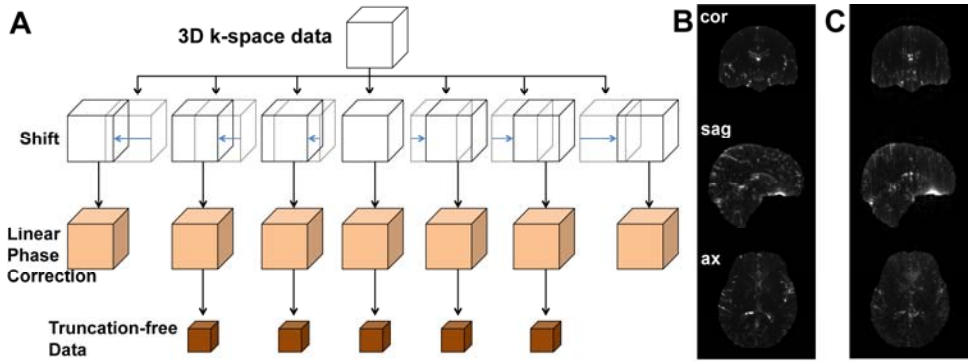

Fig.1 (A) Schematics of P-space calculation with (orange) and without (brown) k-space truncation. Frequency dipolar P-matrices calculated (B) with and (C) without k-space truncation.

Results and Discussion Fig.1B-C show P-matrices acquired by shifting k-space data along S-I direction up to (k_{max}-15) and $k_{max}/2$, respectively. The more details were observable in the P-matrix with full shifts probably due to the reduced spatial resolution in the half-shifted P-matrix, but most features matched between the two calculations. As shown in Fig.2, Signal-to-noise (SNR) and contrast-to-noise (CNR) ratios of P-matrices were improved at longer echo time, although signal losses in regions with short T_2^* were also observed in the later echoes. However, when the difference of P-matrices was normalized by the sum of the P-matrices, SNR and CNR were comparable between images at different echo times but with the corresponding TE-specific contrasts. The contrast in the MSA measured by p-space method was superior at 7T than 3T. Fig.3B shows ~2.5-fold of CNR increase at 7T with better conspicuity as compared to Fig.3A acquired at 3T.

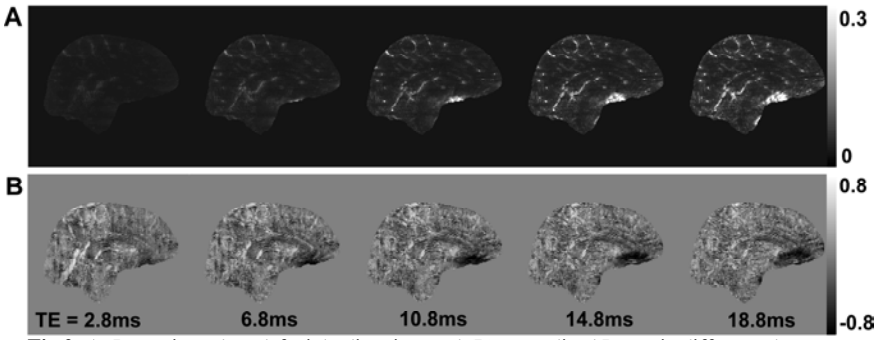

Fig.2 (A) P-matrices along left-right direction, and (B) normalized P-matrix difference between left-right and superior-inferior directions, acquired from 7T.

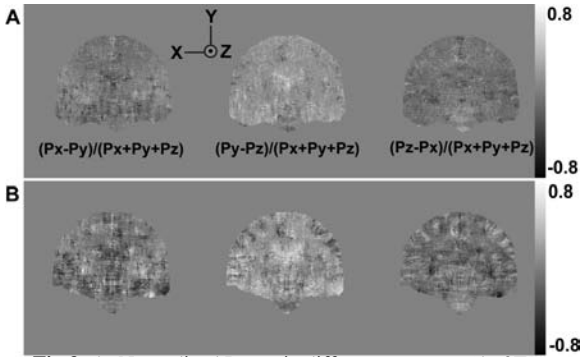

Fig.3 (A) Normalized P-matrix difference maps at (A) 3T and (B) 7T shown in coronal plane.

Conclusion The effect of k-space truncation seems to be compensated when P-matrices were calculated. P-space STI had higher sensitivity at 7T as compared to 3T. T_2^*-weighted STI using multi-echo GRE in addition to preparation pulses will give a new degree of freedom in tensor calculation.

References **1.** Lee J, *PNAS.* 2010; 107:5130-5135, **2.** Liu C, *Magn Reson Med.* 2010; 63:1471-1477, **3.** Wisnieff C, *Neuroimage.* 2013; 70:363-376, **4.** Liu C, *Neuroimage*. 2013;67:193-202.

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