# Common Features in the Orientation Dependence of MR Diffusion, Susceptibility and Relaxation Measurements in the Human Brain in Vivo: Constrained Susceptibility Anisotropy Estimation

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**Target Audience:** Anyone interested in white matter anisotropy

**Introduction:** The dependence on white matter (WM) tract organization has been observed in magnetic susceptibility tensor imaging (STI)[1] and R2* (1/T2*) mapping[2], but STI requires many difficult to acquire orientations of the subject. It is well known that diffusion tensor imaging (DTI) provides WM structural information[3] and has been proposed to guide STI reconstruction[4, 5], but this requires an additional lengthy scan. These parameters are all related to biophysical properties of the WM myelin sheath: STI directly reflects the magnetic property of lipids in myelin, R2* reflects the dispersion-in-voxel of the magnetic field created by the $B_0$-polarized lipids in myelin, and DTI reflects water diffusing around myelin sheath. Here we report the correlations among STI, R2* and DTI, and the feasibility of STI reconstruction guided by R2* tensor map that is derived from the same gradient echo (GRE) data for STI without an additional DTI scan.

**Methods:**

*Image Acquisition*: We approached highly cooperative volunteers (n=7) but only succeeded in obtaining all 12 orientations in two, multi-echo 3D GRE (TR/ TEspacing /#Echoes = 46.9ms/2.6ms/11) and DTI (33 directions b=1000s/mm$^2$ + reference).

*Image reconstruction*: DTI is calculated based on the signal magnitude $\mathbf{A}(\mathbf{b}) = \mathbf{A}(0)\, e^{(-\mathrm{Tr}(\mathbf{bD}))}$, where A is the signal magnitude **D** is the effective diffusion tensor and **b** is the matrix of the time integral of the diffusion weighting gradient, b-matrix.

STI is calculated by solving, $\Delta(\mathbf{k}) = \frac{\hat{\mathbf{B}}_0 \cdot (\mathbf{X} \cdot \hat{\mathbf{B}}_0)}{3} - \hat{\mathbf{B}}_0 \cdot \mathbf{k} \frac{\mathbf{k} \cdot (\mathbf{X} \cdot \hat{\mathbf{B}}_0)}{k^2}$, where **X** is the susceptibility tensor in k-space, $\Delta$ is the relative field inhomogeneity estimated from multi-orientation 3D GRE, and $\hat{\mathbf{B}}_0$ is the $B_0$ direction relative to the subject orientation.

R2* is estimated from the same multi-orientation 3D GRE data according to: $\mathbf{A}(t) = \mathbf{A}(0)\, e^{(-t\hat{\mathbf{B}}_0 \cdot (\mathbf{R2^*} \cdot \hat{\mathbf{B}}_0))}$, with t at various acquired echo times.

*Image Analysis:* The absolute value of the dot product of the principal eigenvectors of two tensors was calculated as their canonical correlation coefficient. Magnetic susceptibility anisotropy (MSA) was estimated using a cylindrically symmetric susceptibility tensor approach reconstructed using DTI and $R_2$* separately as the fiber direction prior [4, 6]. Measurements were made in the splenium, body and genu of the corpus callosum (SCC, BCC and GCC), centrum semiovale (CS) and optic radiation (OR).

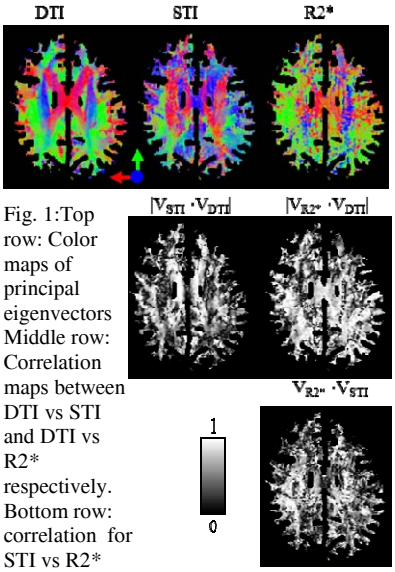


Fig. 1:Top row: Color maps of principal eigenvectors Middle row: Correlation maps between DTI vs STI and DTI vs R2* respectively. Bottom row: correlation for STI vs R2*

**Results:**

*Correlation among DTI, STI and R2* tensor:* Correlation coefficients were summarized in Table 1 and illustrated in Fig.1. There were substantial correlations among DTI, STI and R2* in the corpus callosum. The correlation of R2* and DTI tended to be slightly stronger than that of STI and DTI or that of STI and R2*.

*Estimates of MSA across volunteers:* MSA obtained with DTI prior (SCC(38±39ppb), BCC(35±46ppb) and OR(32±46ppb)) was similar to MSA with R2* prior (SCC(22±47ppb), BCC(15±40ppb) and OR(41±45ppb)), as shown in Fig.2.

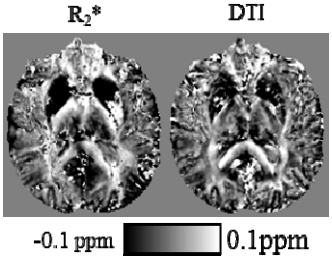


Fig. 2: MSA Maps from R2* and DTI priors with the CSST reconstruction

**Discussion:**

Our preliminary data demonstrate substantial structural similarities between DTI, STI and $R_2$*. The observed correlation of $R_2$* and DTI higher than that of STI and DTI may be explained by the underlying biophysics that both R2* and DTI reflects local tissue properties, while STI may directly reflect the myelin sheath. Differences in processing procedures may also contribute to differences in the reconstructed tensors; DTI and $R_2$* tensors are estimated directly from the magnitude in image space, while STI is a spatial deconvolution of the field inhomogeneity to reveal the myelin susceptibility source.

Our data of similar MSA in constrained susceptibility tensor estimation using DTI and R2* priors suggests that MSA can be estimated using the cylindrically symmetric susceptibility tensor guided by R2* all from the same 3D GRE data without an additional DTI acquisition.

Table 1: Measurements of correlation between eigenvectors across volunteers

| | SCC | BCC | GCC | CS |
|---|---|---|---|---|
| **STI Vs DTI** | 0.52±0.28 | 0.60±0.27 | 0.41±0.27 | 0.41±0.27 |
| **R2* Vs DTI** | 0.62±0.34 | 0.60±0.28 | 0.71±0.28 | 0.47±0.27 |
| **R2* Vs STI** | 0.71±0.28 | 0.42±0.27 | 0.55±0.27 | 0.59±0.27 |

**References:**1. Liu, C., Magn Reson Med, 2010. **63**(6): p. 1471-7. 2. Lee, J., et al., NeuroImage, 2011. **57**(1): p. 225-34. 3. Nucifora, P.G., et al., Radiology, 2007. **245**(2): p. 367-84. 4. Wharton, S. and R. Bowtell, Proc. Intl. Soc. Mag. Reson. Med., 2011. **19**: p. 4515. 5. Li, X., et al., NeuroImage, 2012. **62**(1): p. 314-30.6. Wisnieff, C., et al. in *Proc. Intl. Soc. Mag. Reson. Med.* 2012. Melbourne.