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) and \( R^2* \) (1/T2*) mapping, but STI requires many difficult to acquire orientations of the subject. It is well known that diffusion tensor imaging (DTI) provides WM structural information and has been proposed to guide STI reconstruction, but this requires an additional lengthy scan. These parameters are all related to biophysical properties of the WM myelin sheath: DTI directly reflects the magnetic property of lipids in myelin, \( R^2* \) 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, \( R^2* \) and DTI, and the feasibility of STI reconstruction guided by \( R^2* \) 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/TE=46.9ms/2.6ms/11) and DTI (33 directions b=1000s/mm² + reference).

Image reconstruction: DTI is calculated based on the signal magnitude \( A(b) = A(0)e^{-\left<\text{Tr}(bD)\right>} \), 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, \( \Delta(k) = \hat{B}_0 \cdot \frac{1}{3} (X - \hat{B}_0) - \hat{B}_0 \cdot k \cdot \frac{1}{k^2} (X - \hat{B}_0) \), where \( X \) is the susceptibility tensor in k-space, \( \Delta \) is the relative field inhomogeneity estimated from multi-orientation 3D GRE, and \( \hat{B}_0 \) is the \( B_0 \) direction relative to the subject orientation.

\( R^2* \) is estimated from the same multi-orientation 3D GRE data according to:

\[ A(t) = A(0)e^{-\left<\text{Tr}(b_{\text{eff}}R^2* \hat{B}_0)\right>} \], 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. Measurements were made in the splenium, body and genu of the corpus callosum (SCC, BCC and GCC), centrum semiovale (CS) and optic radiation (OR).

Results: Correlation among DTI, STI and \( R^2* \) tensor: Correlation coefficients were summarized in Table 1 and illustrated in Fig.1. There were substantial correlations among DTI, STI and \( R^2* \) in the corpus callosum. The correlation of \( R^2* \) and DTI tended to be slightly stronger than that of STI and DTI or that of STI and \( R^2* \).

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 \( R^2* \) prior (SCC(22±47ppb), BCC(15±40ppb) and OR(41±45ppb)), as shown in Fig.2.

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 \( R^2* \) 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 \( R^2* \) priors suggests that MSA can be estimated using the cylindrically symmetric susceptibility tensor guided by \( R^2* \) all from the same 3D GRE data without an additional DTI acquisition.

Table 1: Measurements of correlation between eigenvectors across volunteers

<table>
<thead>
<tr>
<th></th>
<th>SCC</th>
<th>BCC</th>
<th>GCC</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>STI Vs DTI</td>
<td>0.52±0.28</td>
<td>0.60±0.27</td>
<td>0.41±0.27</td>
<td>0.41±0.27</td>
</tr>
<tr>
<td>( R^2* ) Vs DTI</td>
<td>0.62±0.34</td>
<td>0.60±0.28</td>
<td>0.71±0.28</td>
<td>0.47±0.27</td>
</tr>
<tr>
<td>( R^2* ) Vs STI</td>
<td>0.71±0.28</td>
<td>0.42±0.27</td>
<td>0.55±0.27</td>
<td>0.59±0.27</td>
</tr>
</tbody>
</table>

References: