Tract Coherence Imaging (TCI): Quantifying the intra-voxel fiber tract heterogeneity

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Introduction

Recently, track-density imaging (TDI) has been proposed as a new super-resolution MRI contrast by computing the local density of fiber pathways using diffusion MRI data [1,2]. One drawback of this approach is that the TDI contrast will depend on the chosen voxel size, complicating quantitative comparisons and, subsequently, the interpretation of the results. In this work, we present a novel approach, dubbed "Tract Coherence Imaging" (TCI), which maps the local consistency of fiber tract orientations for a given voxel resolution. Mathematically, this *tract coherence* (TC) is limited between '0' (random orientations) and '1' (perfectly aligned fiber pathways), providing an elegant framework for quantitative evaluations. With simulations we demonstrate that, in contrast to TDI, in homogeneous regions, TCI does not depend on the voxel size. Finally, we compare TDI and TCI results using real diffusion MRI data.

Methods

Simulations: A synthetic diffusion MRI data set was simulated consisting of three crossing fiber bundles [3].

Acquisition: A diffusion MRI dataset was acquired from a healthy female subject (25y) on a Philips 3T MR system using a SS-SE EPI sequence with 60 gradient directions, a b-value of 2500 s/mm^2, and 2×2×2 mm^3 voxel size.

Tractography: Tractography based on constrained spherical deconvolution (CSD) was performed with maximum harmonics L=8 and fiber orientation distribution threshold of 0.1 in ExploreDTI [4-6].

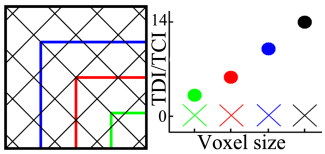

Fig. 1: For a given set of tracts (left), track density (dots) varies with voxel size; whereas tract coherence (crosses) does not.

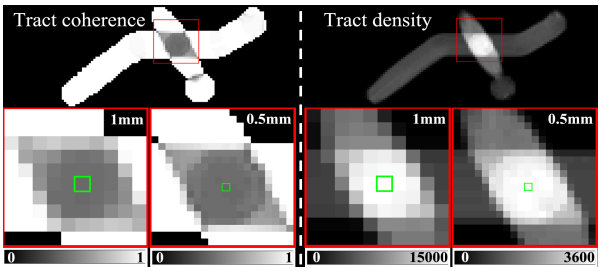

Fig. 2: Simulations showing track density and tract coherence (TC) maps. Track density depends greatly on voxel size (see color bars), whereas the tract coherence TC is less sensitive (TC=0.4187 at 1mm: TC=0.4173 at 0.5mm).

Tract coherence imaging: For every voxel, the tract coherence is calculated as $TC=1-\sqrt{((\beta_2+\beta_3)/(2\times\beta_1))}$, where β_1, β_2 and β_3 are the eigenvalues of the dyadic tensor that describes the local tract orientations [7,8]. The first eigenvector of this dyadic tensor is used to describe the main direction of the tract orientations. A spherical histogram is computed for every voxel, and modeled with spherical harmonics, to determine the number of unique populations and the main orientations of these populations. The simulation analyses have been performed at resolutions of 1mm and at 0.5mm; for the *in vivo* data, a resolution of 0.5mm was used.

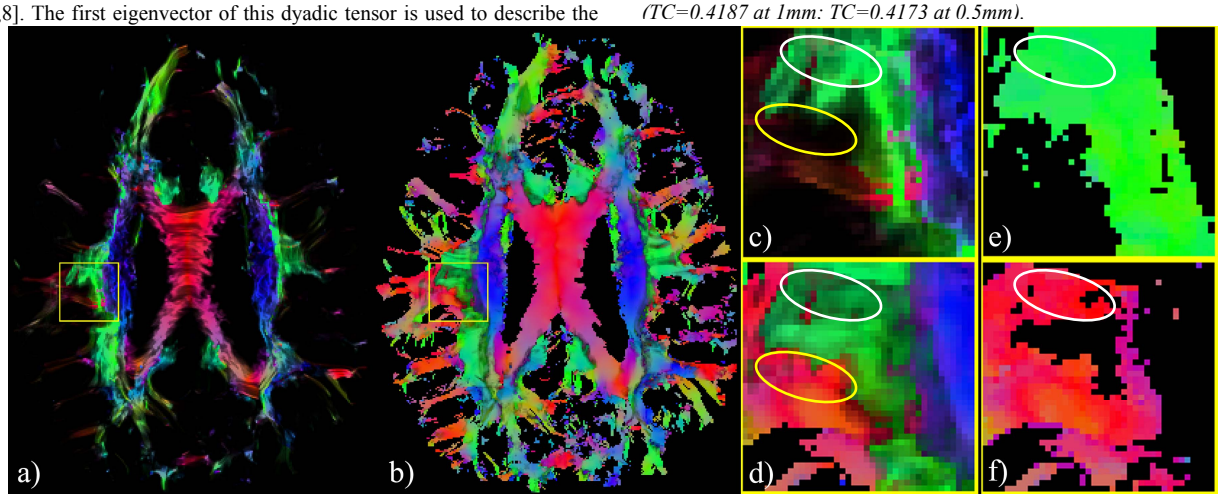

Fig. 3: Color-encoded track-density (a) and tract coherence (TC) (b) maps, with enlargements at the indicated location in c) and d). In regions with low track density (yellow ellipse), the color-encoded TDI map shows little information, whereas there is clear contrast in the color-encoded TC-maps. Additionally, some regions show a clear decrease in tract coherence (white ellipse). Modeling the tract directions per voxel as spherical harmonics shows that the reduced TC in this location is caused by the presence of two distinct fiber populations: anterior-posterior (SLF) (e); and left-right (CC) (f).

Results

The dependence of TDI on voxel size is shown schematically in Fig. 1 Fig. 2 shows that the tract coherence is decreased in the region where three bundles cross (zoomed region). The strong dependence of TDI on the voxel size is absent in the TCI results. Furthermore, a clear difference in TC can be seen where a third bundle (perpendicular to the slice shown) intersects the two bundles oriented in-plane, showing the ability to differentiate between the number of fiber populations. In the *in vivo* data, regions of decreased tract coherence can be observed in locations with known crossing fibers (Fig. 3), e.g., the crossing of the superior longitudinal fasciculus (SLF) and the corpus callosum (CC). Also the difference in contrast information between TDI and TCI can be readily appreciated.

Discussion

Complementary to TDI, we have proposed TCI as a new MRI contrast to investigate the local architectural configuration of tract pathways. Similar to TDI, this approach is not related to the applied diffusion model and can be used in a super-resolution framework. The main benefits compared to TDI, however, are that TCI does not depend on voxel size in homogenous tract configurations and that the TC map is bound between zero and one, facilitating quantitative analyses. Furthermore, the peak fiber orientations can be extracted using spherical harmonics to further understand the architectural complexity in regions of low tract coherence.

References

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