Fiber Density Estimation from Single Q-Shell DWI by Tensor Divergence

Marco Reisert[1], Elias Kellner[1], Henrik Skibbe[1], and Valerij Kiselev[1]
[1]*Medical Physics, University Medical Center, Freiburg, Baden-Württemberg, Germany*

PURPOSE Diffusion-sensitized magnetic resonance imaging provides information about the nerve fiber bundle geometry of the human brain. While the inference of the underlying fiber bundle orientation only requires single q-shell measurements, the absolute determination of their volume fractions is much more challenging with respect to measurement techniques and analysis. A single q-shell measurement provides relative information per volume element, i.e. it is possible to infer the percentage of bundles that pass a voxel with a certain direction, however the absolute fraction is inaccessible. This work uses a conservation equation for fiber orientation densities that can infer the absolute fraction up to a global factor[1]. The idea is based on the assumption that fibers do not terminate in white matter and inspired by the classical mass preservation law in fluid dynamics. In this study we show by simulations on a pseudo ground truth phantom that even for complex, brain-like geometries the method[1] is able to infer the densities correctly. In-vivo results with 81 healthy volunteers scanned with a clinical feasible protocol are plausible and consistent.

METHODS Detailed information about the fiber orientations is provided by the joint fiber orientation distribution (FOD) $p(\mathbf{n},\mathbf{r})$. This function is not directly accessible with single q-shell DWI. The observable quantity is rather the conditional FOD $p(\mathbf{n}|\mathbf{r})$, which does not provide any information about the absolute density of fibers $\rho(\mathbf{r})$ per voxel. These quantities are related by $p(\mathbf{n},\mathbf{r}) = \rho(\mathbf{r})\, p(\mathbf{n}|\mathbf{r})$. The goal is to find $\rho(\mathbf{r})$ given the conditional $p(\mathbf{n}|\mathbf{r})$. To achieve this, a cost functional is constructed by using the principle of fiber continuity[1,2], which assumes that fibers appear to be locally straight. The main idea is to require the change $n_j\partial_j p(\mathbf{n},\mathbf{r})$ to be small in magnitude, where n_i is the current fiber direction. Consider the vector field $n_i n_j \partial_j p(\mathbf{n},\mathbf{r})$. This vector points in an arbitrary selected direction $\boldsymbol{n} = (n_1, n_2, n_3)$ and its magnitude equals the gradient of the FOD in this direction. This vector is integrated over all fiber directions to obtain an integral characteristics of a voxel:

$$k_i(\mathbf{r}) = \int_{S_2} n_i n_j \partial_j p(\mathbf{n},\mathbf{r})\ |d\mathbf{n}| = \partial_j \int_{S_2} n_i n_j\ p(\mathbf{n},\mathbf{r})\ |d\mathbf{n}| = \partial_j P_{ij}(\mathbf{r})$$

To solely suppress source terms and leave the curvature untouched the vector field **k** undergoes a projection by the tensor $T_{ij}(\mathbf{r}) = \int n_i\, n_j\, \partial_j\, p(\mathbf{n},\mathbf{r})$. The following cost function is minimized:

$$J_{TD}(\rho) = \int_\Omega (\partial_a P_{ia}) T_{ij} (\partial_b P_{jb}) dV - \int_\Omega \rho dV$$

The optimization is implemented by a finite element discretization and solved on a standard PC in a few minutes. To demonstrate the validity of the proposed method a global tractogram is generated, which is used to generate a 'pseudo' ground truth FOD. Secondly, on 81 volunteers (b-values 1 μm^2/ms, 64 directions) CSD-based[3] FODs were derived and used as input for the approach.

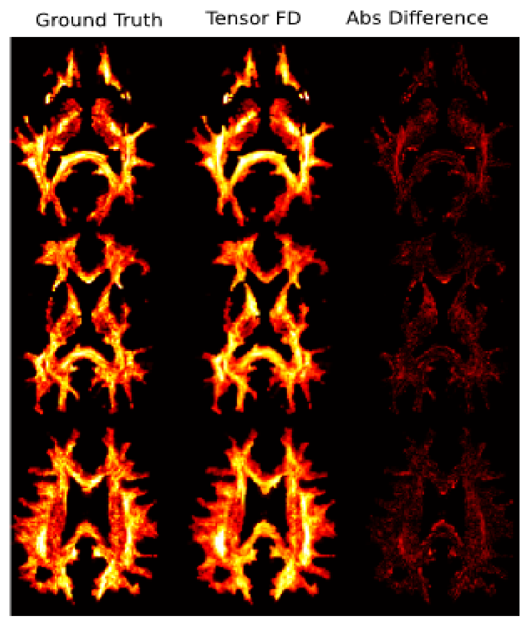

Figure 1: Comparison of pseudo Ground Truth with derived fiber densities

RESULTS Comparison of pseudo ground truth and tensor-divergence based densities (TFD) are shown in Figure 1. Figure 2 shows TFD for the corpus callosum (CC) (a) of randomly selected volunteers, the average CC over 81 subjects (b) and transversal slices of the average map (c).

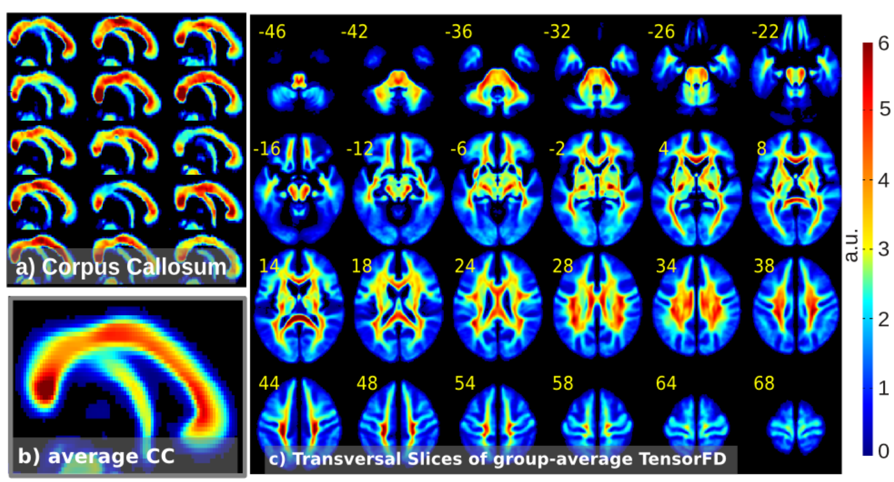

Figure 2: In-vivo results of TFD. a) CC of 12 individuals, b) average CC, c) transversal slices of average TFD with corresponding MNI z-coordinate.

DISCUSSION and CONCLUSIONS With the pseudo ground truth experiment we have shown that the tensor divergence approach is able to cope with the complex geometry of the human brain and derives up to discretization artefacts the correct densities, although boundary conditions are not taken into account and are assumed to be unknown. The in-vivo experiments suggest that the fiber density in human brain is not constant, which is in contrast to other fiber density indicators like the angular mean of CSD-based FODs. In particular in crossing regions TFD is high. On the other hand, the inferred densities go in line with the current anatomical knowledge of the human brain: high densitities in the major tracts like the cortical spinal tract, superior longitudinal tracts or the corpus callosum.

References: **[1]** Marco Reisert et al, "Tensor Divergence for Fiber Density Estimation", Proceedings of MICCAI 2012, **[2]** Marco Reisert et al, IEEE TMI, 2011, Vol 30(6):1274 -1283, **[3]** J.D.Tournier et al, Neuroimage 2008, Vol 42(2):617-25.