Deriving scalar maps from Diffusion Spectrum MRI

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Introduction

The advantage of Diffusion Spectrum MRI (DSI) is to map diffusion without a priori. Unlike DTI, it makes it possible to measure realistically diffusion of complex brain architecture. As DSI acquisitions are getting shorter and consequently clinically feasible, it is necessary to have scalar maps available in order to easily visualize the various features of the local diffusion pdf. From DSI we can calculate the widely used scalar maps like mean diffusion (MD) or fractional anisotropy (FA) [1] and also extract other contrasts reflecting different features of the diffusion pdf. Here we present how to derive such maps from a 10 min long whole brain DSI acquisition.

Material

We perform a whole brain study of a healthy volunteer on an Achieva 3T Philips scanner. We use a diffusion weighted single shot EPI sequence with the following timing parameters: TR/TE/Delta/delta = 3000/100/47.6/35 ms and b-max = 12000 mm^2/s. Q-space is sampled over an hemisphere with 129 points and the data reconstructed according to a standard DSI scheme [2], hence producing a 3D diffusion pdf in every voxel. The acquisition block is made of 32 slices of a 128x128 matrix with a spatial resolution of 2x2x3 mm3. The acquisition time is 9 minutes.

Methods and Results

With this procedure we obtain a full 3D diffusion pdf for every brain voxel. As the direct representation of this 6-dimensional data is problematic, we propose hereafter a series of scalar maps derived from the 3D pdf ($p(\mathbf{x})$, with $\mathbf{x}$ being the diffusion displacement). The MD corresponds to the total variation of the pdf: MD = trace(E[$\mathbf{x}\mathbf{x}^T$]), where E[.] is the expectation, and yields Fig. 1. Entropy maps are computed in the following way H = -E[$\log_2(\mathbf{x})$], see Fig 2. The sharpness of a function is defined as the ratio between two different l-norms. Here we take the ration between the l^4-norm ($\|.\|_4$) and l^2-norm ($\|.\|_2$). We define the diffusion sharpness (DS) as: DS = $\|p\|_4(\|p\|_2)^{-2}$. We consider the orientation of maximal diffusion as the axis along which the pdf has maximal variance; we call this axis the lambda1 vector in reference to the first eigenvector of the diffusion tensor. We then encode this maximal diffusion axis in RGB and weight the color intensity with the DS (Fig 4). Lambda1 is the variance of the pdf along the maximal diffusion axis and mapping this coefficient yields Fig 5. Fig 6 maps in color the maximal diffusion axis and weights its intensity with lambda1. The average diffusion coefficient in the directions perpendicular to the maximal diffusion axis is sometimes also of interest, therefore we map in Fig 7 the variance of the pdf in a plane perpendicular to the maximal diffusion axis. Fig 8 is the equivalent with color indicating the orientation of maximal diffusion. Finally in Fig 9 we compute the generalized FA (GFA) [3] after having computed the orientation density function (ODF) from the pdf. Fig 10 is the color version of Fig 9.

Discussion

DSI maps the 3D diffusion pdf completely and subsequently produces data of 6 dimensions which are problematic,(as the diffusion tensor), to be visualized directly. Hence, scalar maps which summarize different features of the pdf are useful. Some of the scalars presented are familiar to DTI scientists as MD and GFA. However, we have introduced many other contrasts that can not be extracted from DTI and are of great interest. Entropy is a measure of unpredictability in probability theory and here gives information of the spreading of the pdf, different from MD. A very interesting feature is the DS which provides an excellent gray/white matter and csf contrast and seems robust to fiber crossings, unlike GFA. It is a measure that is sensitive to the concentration of a distribution. When studying pathology, it has become evident over the last years that with DTI lambda1 and mean(lambda2,lambda3) are also useful, reflecting tract disruption and membrane permeability. Here we propose DSI equivalents that are called lambda1 and perp. lambda1 measuring the diffusion coefficient along the principal fiber tract and in the plane perpendicular to it.

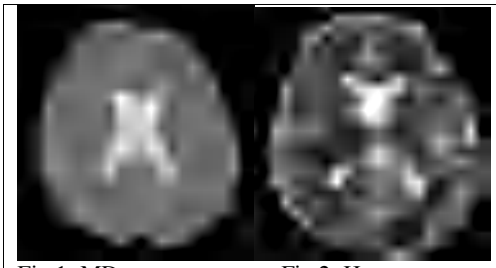

Fig 1: MD Fig 2: H

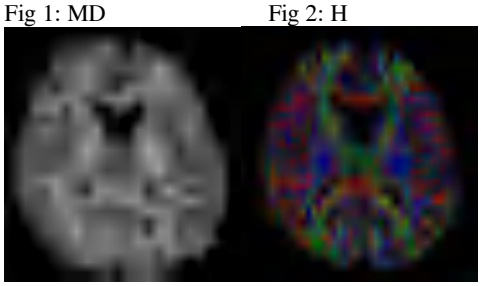

Fig 3: DS Fig 4: Color DS

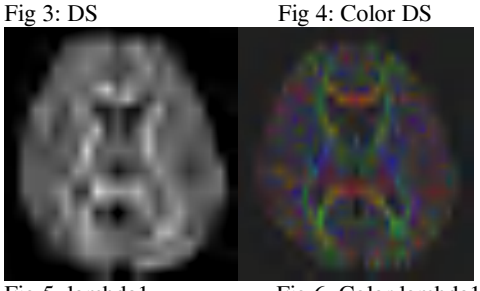

Fig 5: lambda1 Fig 6: Color lambda1

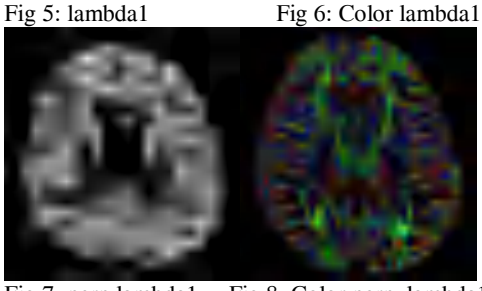

Fig 7: perp lambda1 Fig 8: Color perp. lambda1

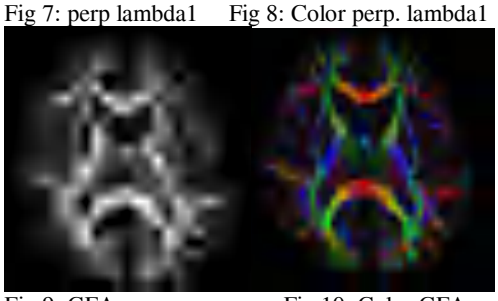

Fig 9: GFA Fig 10: Color GFA

Conclusion

We proposed scalar maps for DSI by computing summary statistics of various kinds. Now that DSI scans can be performed in less than 10 minutes and therefore clinically feasible, such maps are potentially useful to study all kind of pathologies as MD and FA is for DTI.

References [1] Basser P et al. J. Magn. Reson. Med. 111:209-19 (1996) [2] Wedeen V, Hagmann P et al. Magn. Reson. Med. 54:1377-86 (2005) [3] Tuch DS. Magn. Reson. Med. 52:1358-72 (2004).

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