A Statistical Approach for Creating Anisotropy Maps of the Brain Using q-Space Diffusion Weighted Images

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Introduction

One of the applications of diffusion tensor imaging (DTI) is creating anisotropy maps such as the fractional anisotropy (FA) map which can be used for distinguishing isotropic and anisotropic media, specifically structures in the brain [1]. DTI based anisotropy maps are created based on the assumption that diffusion follows a Gaussian model. This is not always true, especially in the case of voxels representing multiple orientation fibers [2]. This will lead to low intensities in anisotropy maps in areas which have higher fiber concentrations with crossing fiber. Alternative methods such as information theory approaches have been proposed for creating anisotropic maps that deal with this problem [3]. In this abstract, we introduce a statistical approach to this problem using q-space DTI measurements.

Materials and Methods

MR images were acquired on a 4.7-Tesla Bruker scanner. The MRI images consisted of a set of q-space DTI images of an ex-vivo rat brain. For acquiring these images, the diffusion probability function was measured using a multislice spin-echo diffusion-weighted imaging (DWI) sequence (32mmx32mm FOV; 128x128 matrix; 16 slices with 1mm slice thickness; 1600ms TR, repetition time; 38ms TE, echo time) with diffusion gradients in 128 directions uniformly distributed on the surface of a sphere for q-space DTI measurement. Two 12ms diffusion-weighted gradient pulses separated by 20ms, one on either side of the refocusing 180 degrees RF pulse, was approximately 95.5mT/m to obtain an image with gradient b-value 1200 s/mm^2. Total scan time was 7.4h for NA=1. The rat was a subject of a controlled cortical impact (CCI) model of traumatic brain injury (TBI) study and treated with bone marrow stromal cells (MSCs). The ex-vivo images were acquired at 7 weeks after the TBI onset. After acquiring the MR images, the ex-vivo brain was prepared for histology and was stained using Bielshowsky (axons; black) and Luxol fast blue (myelination; blue). Our method of creating the anisotropy map is based on calculating the deviation of diffusivity from a sphere in each voxel using all the 128 q-space measurements. If the voxel belongs to an isotropic medium, diffusion will also be isotropic in all directions. In this case, considering the gradient directions for each measurement, the 3D diffusion vectors will form a sphere and the standard deviation (SD) of the length of these vectors will be small (the noise and measurement error will cause the SD to be non-zero). Any deviation of this 3D shape from a sphere, either dominated in one direction or crossing fiber, will cause an increased SD. Based on this fact, we calculate the standard deviation of the diffusion vector lengths for every voxel and create a new anisotropy map which can be named the SD map. If diffusion is constrained by tubular structures this will cause the SD to have an increased value in the map. This value would depend on the shape that the diffusion vectors form. Orientation distribution functions (ODF) of q-ball data were calculated with the Camino software [4]

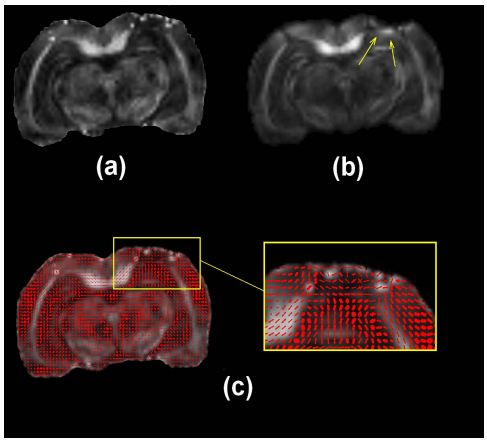

Figure 1. The (a) FA, (b) SD maps and (C) q-ball ODF icons of a single slice of the rat brain with TBI. The yellow arrows in (b) show the location of the axons in the SD map that are not observed in the FA map.

Results

Figure 1 shows the FA map (a), the SD map (b) and the q-ball orientation distribution function (ODF) overlaid on the FA map from a single slice of the rat brain. The ODFs show the orientation of the fibers in each voxel. Figure 2 shows the corresponding Bielshowsky and Luxol fast blue staining of this slice. White matter reorganization, confirmed by an increase in axons (black; Figure 2-1, 3, and 4) and myelination (blue; Figure 2-1, 3, and 4), coincided with increases in SD after TBI in the TBI boundary. However, FA did not correspond to the increase in axons at the base of the lesion (yellow arrows in 1 of Figure 2) where more fiber crossing was detected on the q-ball orientation map (Figure 1c). FA only corresponds to the axon increase in the areas with higher number of single rather than crossing fibers.

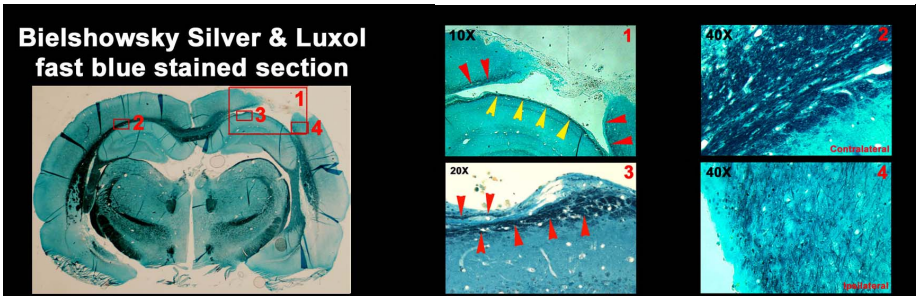

Figure 2. Bielshowsky and Luxol fast blue staining images measured from the fixed rat brain. 1 to 4 are high- magnification images from the boxes in the left panel

Conclusion

Our data suggests that the SD map may provide more anisotropy information about the white matter structure in the brain, especially in areas with crossing fiber. These results also show the correlation of the FA and the SD maps in the areas with more single fibers.

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