A novel DTI method for analyzing the diffusion of water in retina

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Abstract - In this paper, we present a novel DTI method for analyzing the diffusion of water in retina. Studies on DTI datasets from mouse eyes have shown that the diffusivity in the layer of retina has an organized structure (fig.1a). In this work, we analyze this structure by evaluating a quantitative measure using the following method. We represent each diffusion tensor of the retinal layer by a multivariate Gaussian probability, whose isosurfaces have the same orientations as the primary eigenvector of the corresponding diffusion tensor. The weighted sum of these probabilities formulates a mixture of Gaussians [1]. In our experimental results we show that this mixture of Gaussians takes its global maximum value near the center of the eye (focal point). In our experiments we used 3D DTI datasets acquired from three normal mouse eyes, and an additional one eye that was subjected to focal laser treatment, resulting in disruption of the BRB. In the latter dataset the global maximum of the probability is far from the center of the eye, as a result of the changes in the diffusion properties.

Motivation – The primary orientation of the diffusivity in the layer of retina appear to be towards to the center of the eye (fig. 1a). The diffusion properties of the eye are changed in pathogenic cases. For our study we used lasered eyes as a model for pathogenic eyes, since the laser technique induces similar conditions regarding the permeability in the retinal layers. By using information about the diffusivity from DTI datasets, we propose a method to discriminate between eyes with normal and abnormal diffusion properties.

Proposed Method – In the first step of our method we extract the region of the 3D DTI dataset corresponding to the retinal area. This can be done by thresholding the diffusion weighted images, in which the retina has more bright intensities compared to the rest of the regions of the eye. After having extracted the retinal regions we compute the 3x3 eigenvector matrix $\boldsymbol{V}_i$ from the diffusion tensor matrix $\boldsymbol{D}_i$ of each voxel of the extracted region. Here the index 'i' denotes the lattice index of the voxels in the retinal region. We assume that the first column of the matrices $\boldsymbol{V}_i$ correspond to the principal eigenvector of $\boldsymbol{D}_i$. For each voxel we formulate a multivariate Gaussian probability with mean the 3D coordinates $\boldsymbol{p}_i$ of the voxel and covariance matrix $\boldsymbol{V}_i\boldsymbol{\Sigma}\boldsymbol{V}_i^T$, where $\boldsymbol{\Sigma}$ is a diagonal matrix with elements $[\sigma, 0.25, 0.25]$. Using a large value for $\sigma \sim 10^5$ the isosurface of the probability takes an almost cylindrical shape parallel to the primary eigenvector and having radius equal to half pixel. Using these probabilities we formulate a mixture of Gaussians $p(\boldsymbol{x}) = 1/n \sum_i N(\boldsymbol{x}; \boldsymbol{p}_i, \boldsymbol{V}_i \boldsymbol{\Sigma} \boldsymbol{V}_i^T)$ and we evaluate it for every lattice point of the original 3D DTI volume (fig. 1).

Experimental Results - Fig. 1 illustrates the proposed method, showing a 2D slice from a DTI dataset, the extracted retinal region and the mixture of Gaussians evaluated for each point of the slice. In fig. 2 we present in 3D the computed probability for 3 normal eyes and an eye where a focal lesion was induced by laser (upper row) and the corresponding points of global maxima (lower row). In the case of normal eyes the global maximum is located near the center of the eyes, while in the last dataset it is located near the retina. This validates our method and demonstrates a way to discriminate eyes with normal from eyes with abnormal diffusion properties. Figures are explained with more details in their captions.

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Reference [1] Titterington, D., A. Smith, and U. Makov "Statistical Analysis of Finite Mixture Distributions," John Wiley & Sons (1985).

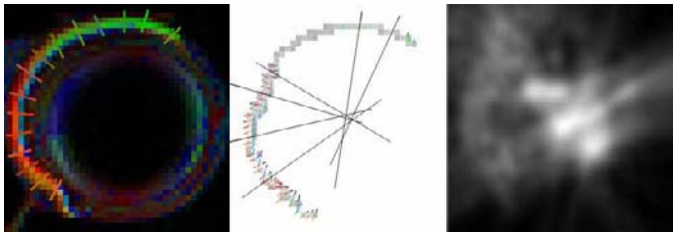

Figure 1. Illustration of the proposed method. **Left**: The eigenvector field of the retina of a 2D slice from a mouse eye. The R,G,B colors of the vectors are their X,Y,Z components. Note that the orientation of the eigenvectors is pointing the center of the eye. **Middle**: The extracted region corresponding to the retina. Some of the isosurfaces of the Gaussian probabilities are plotted as thin cylindrical surfaces. (Here they appear as lines.) These lines intersect near the center of the eye, where the mixture of Gaussians has the global maximum. **Right**: The evaluated mixture of Gaussians for every point of this slice.

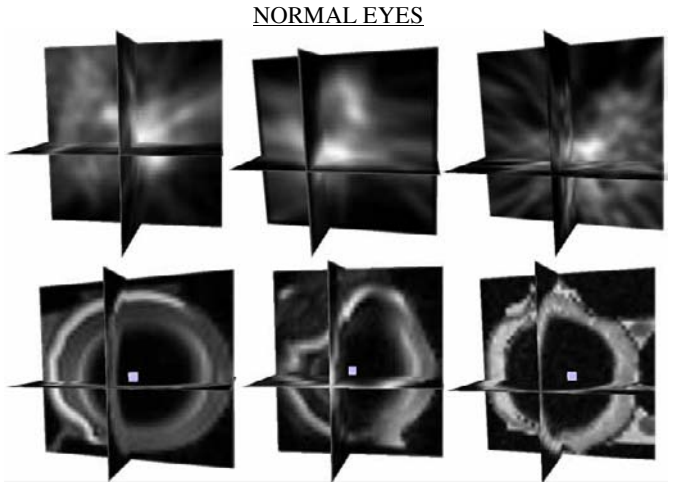

Figure 2. Upper row) The evaluated probability in 3D for three DTI datasets of normal eyes and a DTI dataset of a damaged by laser eye. Lower row) The corresponding locations of maxima plotted as points in 3D together with diffusion weighted images Note that in the three first datasets the points of maxima are located near the center of the eyes. In the last dataset it appears near the retinal layer, due to changes in the diffusion properties of this sample.

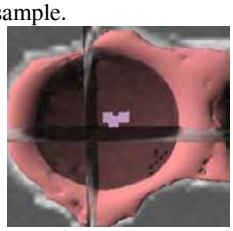

Figure 3. The maximum probability points of the three normal eyes projected on a 3D eye atlas. Note that the points form a cloud near the center of the eye.