Voxel-Based Analysis of the Optic Radiation Using Diffusion Tensor Imaging in Glaucoma Patients

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Purpose

To establish a registration based framework for the determination of local changes of the optic radiation due to glaucoma using Diffusion Tensor Imaging (DTI).

Diffusion Tensor Imaging

- The only imaging modality that allows fiber identification non-invasively and in-vivo [2]
- Diffusion tensor derived parameters:
  when λ_1, λ_2 and λ_3 are the diffusion tensor eigenvalues in a descending order then
  Axial Diffusivity (AD) $= \lambda_1$
  Radial Diffusivity (RD) $= (\lambda_2 + \lambda_3)/2$
  Mean Diffusivity (MD) $= \lambda = (\lambda_1 + \lambda_2 + \lambda_3)/3$

  Fractional Anisotropy (FA) $= \sqrt{\frac{3}{2}} \frac{\sqrt{(\lambda_1-\lambda)^2+(\lambda_2-\lambda)^2+(\lambda_3-\lambda)^2}}{\sqrt{\lambda_1^2+\lambda_2^2+\lambda_3^2}}$

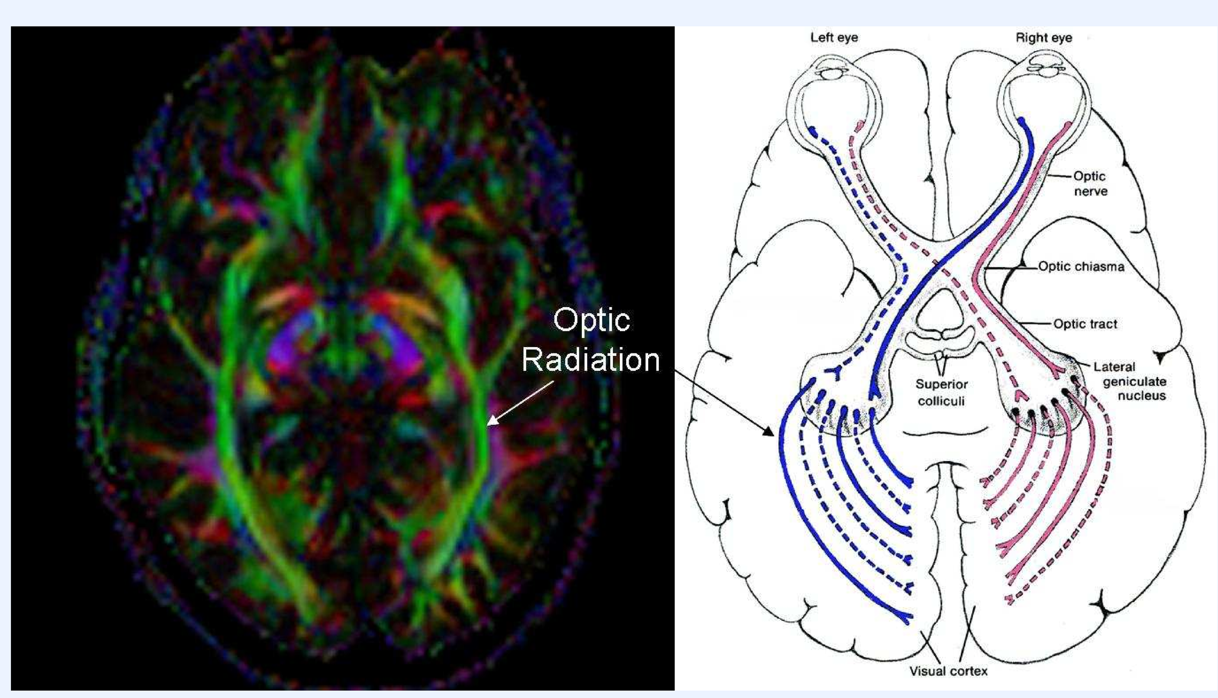

Figure 1: Illustration of the human visual system (right) and the corresponding optic radiation shown on a DTI axial slice (left). (visual system image with permission to reuse: Matlin, M. W. and Foley, H. J.: Sensation and Perception. Allyn and Bacon)

Data

Glaucoma group: 13 subjects with primary open angle glaucoma (4 males and 9 females) with an average age of 63±12.5 years.

Control group: 10 subjects (4 males and 6 females) with an average age of 56.9±11.9 years.

Acquisition:

- **Scanner:** 3T-MRI scanner
- **Protocol:** single-shot, spin echo, echo planar imaging (EPI) as an imaging sequence with repetition time (TR) 3400 ms, echo time (TE) = 93 ms, field of view (FoV) 230 x 230 mm^2. Diffusion weighting with a maximal b-factor of 1000 s/mm^2 along 15 icosahedral directions complemented by one scan with b = 0 with seven signal averages.
- **Acquisition matrix:** size of 128 x 128 reconstructed to 256 x 256. Twenty five axial slices with an intra-slice resolution of 1.8 x 1.8 mm^2 and 5 mm thickness.

Method

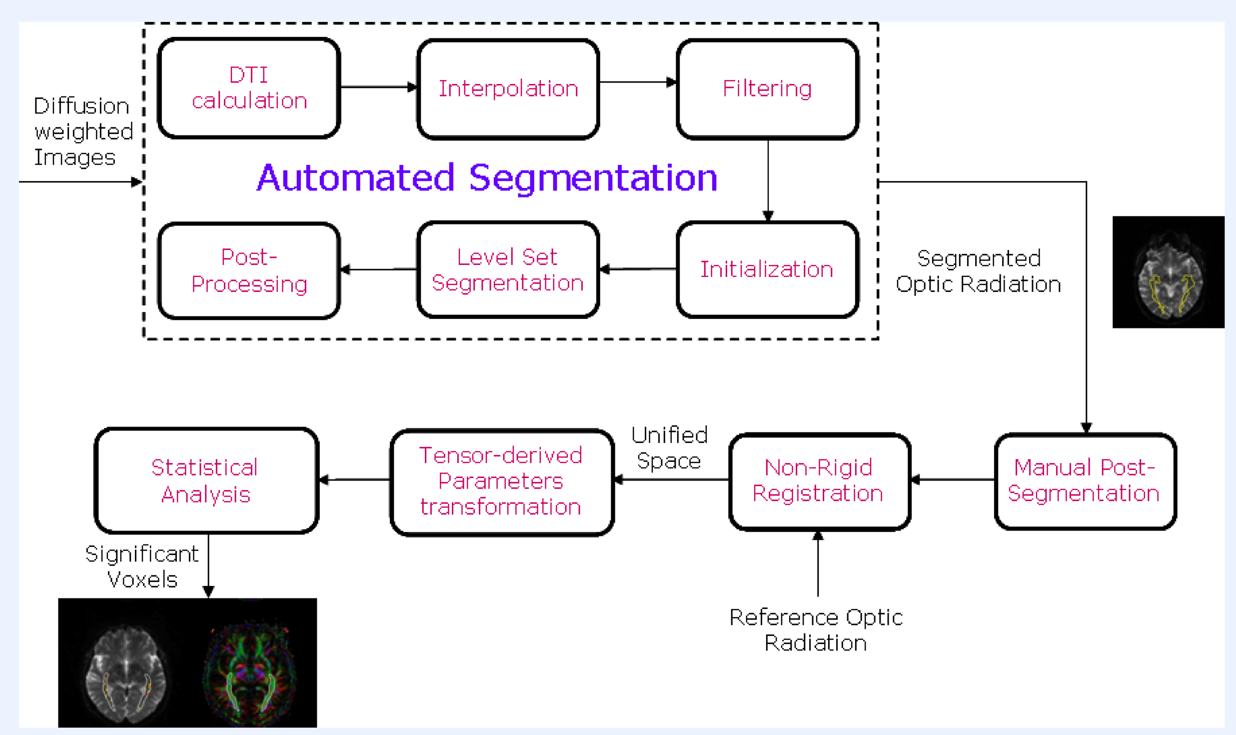

Figure 2: Overview of the proposed analysis framework for voxel based morphometric analysis using DTI

The proposed framework consists of the following steps:

1. **Automated segmentation of the optic radiation [1]**
2. **Manual adjustment of segmentation** to remove structures like lateral geniculate nucleus (LGN) and correct segmentation errors.
3. **Shape-based registration**
   - Shape similarity of the optic radiation in the LGN-slice allows registration and voxelwise comparison.
   - Reference is the normal subject with maximum optic radiation size.
   - Non-rigid registration of all subjects to the unified space of the reference
4. **Transformation of diffusion parameters maps to the unified space**
   Using the transformation fields from the registration, the diffusion related parameters and the fractional anisotropy maps are transformed to the unified space.
5. **Statistical analysis**
   The transformed maps are analyzed voxelwise using Mann-Whitney U test.

Results

- Statistical significance is considered when the p-value is less than 0.05 and 0.1.
- The analysis is applied to FA,AD,RD and MD.

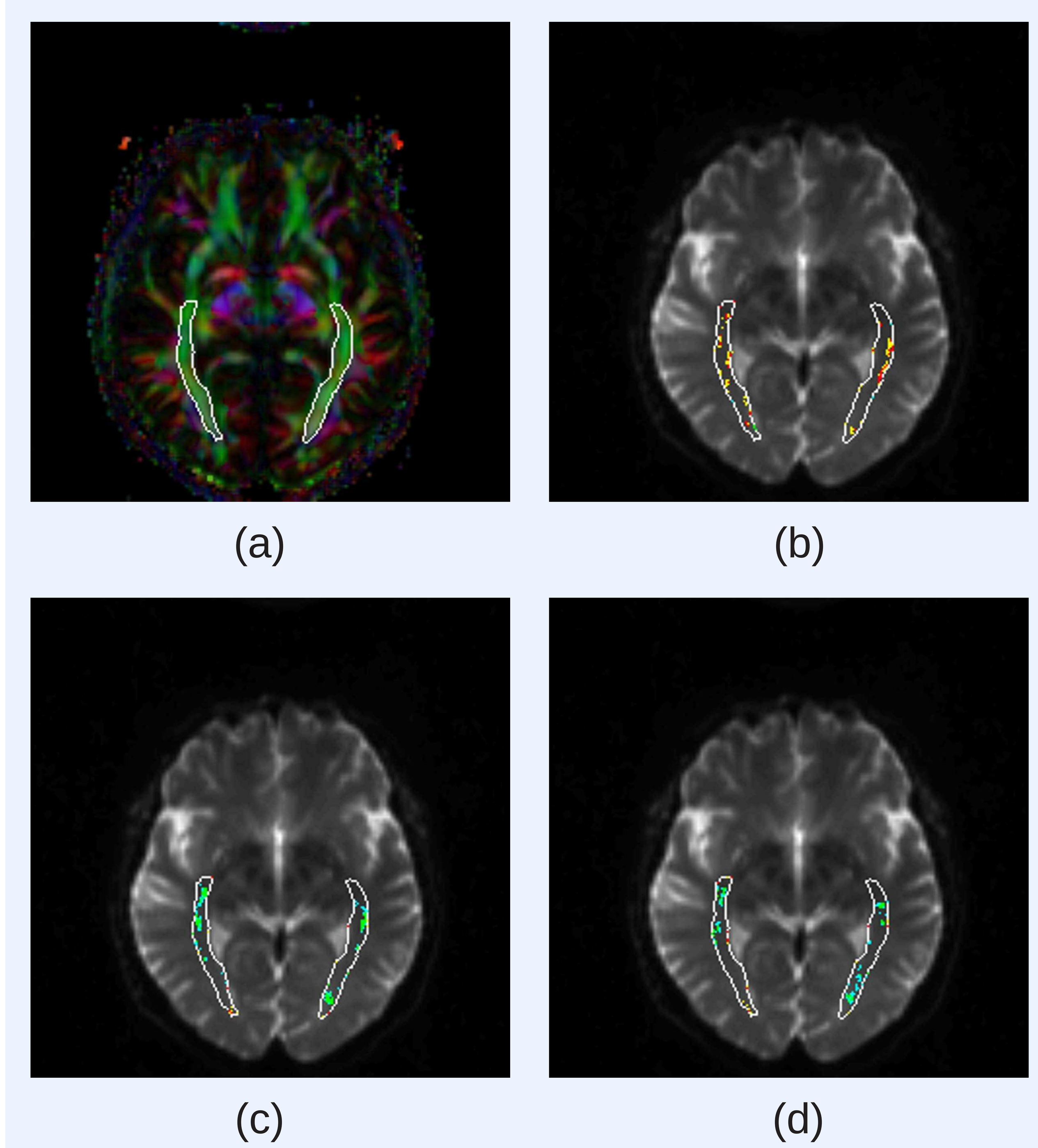

Figure 3: Optic radiation on the reference subject (a) and the significant optic radiation voxels based on the analysis of : (b) Fractional anisotropy (FA), (c) Radial Diffusivity (RD), and (d) Mean Diffusivity (MD). Color code is as follows: Red and Yellow: significant voxels with normal mean value $>$ glaucoma mean value with p-value $\leq$ 0.05 and p-value $\leq$ 0.1 respectively, Green and Cyan: significant voxels with normal mean value $<$ glaucoma mean value with p-value $\leq$ 0.05 and p-value $\leq$ 0.1 respectively.

FA analysis : Concentration of decreased FA voxels in glaucoma subjects is found near the medial edges of the optic radiation.
RD and MD analysis : Radial and mean diffusivities are increased for glaucoma patients in the proximity of the Meyer loop and visual cortex.
AD analysis : Effect on axial diffusivity is scattered and does not lead to significant information (not shown).

Conclusion

- The proposed framework is robust and efficient for voxel-based analysis of the optic radiation in the presence of glaucoma.
  - Shape based registration avoids the dependence on tensor derived parameters which are affected by the presence of glaucoma.
  - Results are in agreement with the previous glaucoma studies.
- Results of FA analysis suggest that the optic radiation suffers from decreased fiber integrity (axonal degeneration) near the edges.
- The optic radiation suffers from demyelination in the proximity of the Meyer loop as suggested by the RD analysis results.
- DTI shows a great potential in localizing the effect of glaucoma on the optic radiation.

Support

The authors gratefully acknowledge funding of and the Erlangen Graduate School in Advanced Optical Technologies (SAOT) by the German National Science Foundation (DFG) in the framework of the excellence initiative and the German academic exchange service (DAAD).

Commercial Relationship

A. El-Rafei, None; T. Engelhorn, None; S. Wärntges, None; J. Hornegger, None; G. Michelson, None; A. Dörfler, None.

References

[1] A. El-Rafei, J. Hornegger, T. Engelhorn, A. Dörfler, S. Wärntges, G. Michelson. Automatic Segmentation of the Optic Radiation using DTI in Glaucoma Patients. In: Computational Vision and Medical Image Processing - VipIMAGE 2009 (International Conference VipIMAGE 2009 - II ECCOMAS Thematic Conference on Computational Vision and Medical Image Processing, Portugal 14-16.10.2009) Portugal : Taylor and Francis 2009, pp. 293-298.

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