

FIBER TRACTOGRAPHY AND TRACT SEGMENTATION IN MULTIPLE SCLEROSIS LESIONS

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1. Motivation

- Diffusion tensor imaging provides rich information about human brain connectivity in vivo.
- Current methods for fiber tractography or tract segmentation do not address white matter pathologies such as multiple sclerosis lesions.
- WM lesions can alter the diffusion tensor characteristics.
- Effect of lesions should be compensated.

3. Diffusion Data Correction

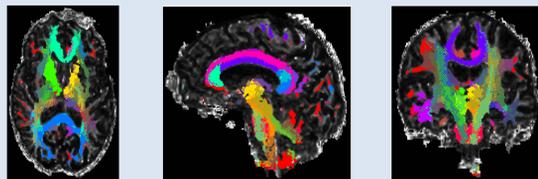
FACT [3]

- A popular tractography algorithm :
 - Searches for fiber tracts based on the tensor directions
 - Searches areas with $FA > FA_{\min}$
- Lesions may decrease the FA
- Correction algorithm for FACT inside lesion areas:

$$FA_i \leftarrow FA_i + FA_{\min}$$

- Ensures that all the lesion areas are searched

DOTS [4]



- A direct tract segmentation algorithm:
 - Searches for fiber tracts based on the tensor directions
 - Combines the diffusion tensor information with prior knowledge from shape and direction atlases
 - Based on Markov random fields
 - Models 3 structures: isotropic, single tract, crossing tracts
- Correction algorithm for DOTS inside lesion areas:
 - Prevent lesion voxels to be segmented as an isotropic region

FACT+DOTS

- DOTS was applied to FACT results to label the tracts:
 - DOTS generates volumetric labels of major fiber bundles
 - A tract is labeled as a DOTS bundle if:
 - at least 50% of the tract was included in the DOTS mask
 - the tract at least traversed 10 voxels

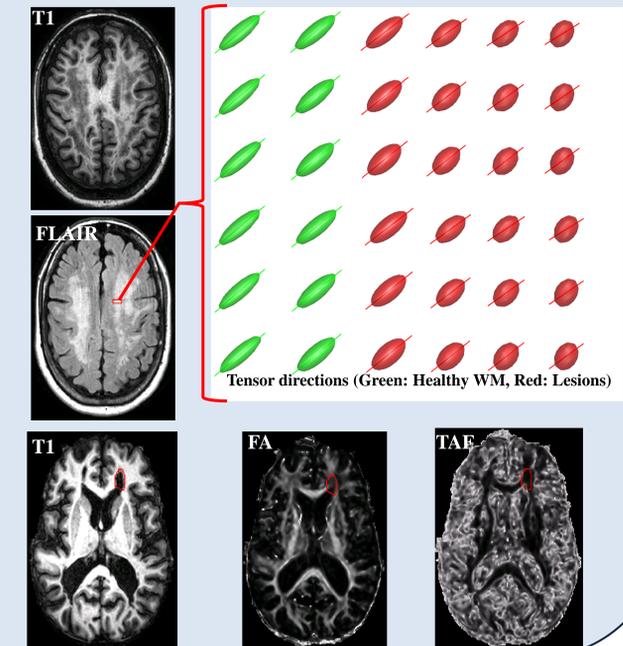
2. Effect of Lesions on the Diffusion Tensor

- Fractional anisotropy (FA) is known to be lower in MS lesions [1]
- Tensor alignment factor (TAF)

$$TAF_i = \frac{1}{26} \sum_{j \in N_i} \arccos \left(|v_i \cdot v_j| \right),$$
 where v is the principal direction.
- TAF measures the directional uniformity
- Lesion types (Based on intensities on T1 and FLAIR):
 - Type 1: hyper intense on FLAIR, like GM on T1
 - Type 2: hyper intense on FLAIR, like GM and CSF on T1
 - Type 3: hypo intense on FLAIR, like CSF on T1
- This categorization more or less coincides with lesion severity
- Lesion-TOADS[2] is used to segment lesions from healthy WM

In all the 3 lesion types (from 3 different MS cases), TAF differences between healthy WM and lesions were small, implying tensor directions in MS lesions are relatively preserved.

Lesion type	Healthy WM		Lesion	
	TAF	FA	TAF	FA
1	0.36±0.20	0.36±0.15	0.32±0.18	0.30±0.12
2	0.38±0.21	0.40±0.17	0.35±0.21	0.31±0.13
3	0.37±0.21	0.39±0.18	0.34±0.17	0.30±0.13



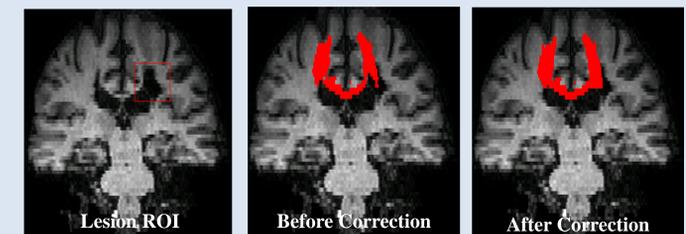
4. Results and Conclusions



Result of the correction step on FACT (superior longitudinal fasciculus), dark blue represents the shortest and light red represents the longest tracts.

- FACT was applied to 10 MS subjects with 3 settings
 - FACT 1: $FA_{\min} = 0.2$ (default values in many of the studies using FACT) with correction
 - FACT 2: $FA_{\min} = 0.2$ without correction
 - FACT 3: $FA_{\min} = 0.1$ without correction
- FACT 3, includes most of the lesions (because of lower FA_{\min}), but has smaller WM coverage
 - more artificial tracts inside GM
- FACT 1, generates significantly higher number of tracts in comparison to FACT 2, while having similar FA and WM coverage

ID	FACT 1		FACT 2		FACT 3	
	FA	counts	FA	counts	FA	counts
Mean	0.38	357276	0.38	354773	0.30	606690



Result of the correction step on DOTS (corpus callosum).

- FACT1 and FACT2 results segmented by DOTS were compared based on lesion load along the tracts
- Tracts with significantly increased inclusion of lesions after correction:
 - frontal, posterior and superior parts of the corpus callosum, left and right fronto-occipital fasciculus (both superior and inferior parts), left and right posterior thalamus radiation, left optic radiation, right cingulum

The introduced correction step significantly improves the performance of the conventional tractography algorithms in brains with lesions. Without such a step, a large portion of the tracts that pass through lesions are not detected and quantitative measurements of FA, MD, size or connectivity along those tracts are likely to be erroneous.

[1] Y. Ge, "Multiple sclerosis: the role of MR imaging", 2006. [2] N. Shiee, et al, "A topology-preserving approach to the segmentation of brain images with multiple sclerosis lesions", 2010. [3] S. Mori, et al, "Three-dimensional tracking of axonal projections in the brain by magnetic resonance imaging", 1999. [4] P.-L. Bazin, et al, "Efficient MRF segmentation of DTI white matter tracts using an overlapping fiber model", 2009.

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