Gaining Insights Into Multiple Sclerosis Lesion Characteristics from Brain Tissue Microstructure Information: A Multi-Compartment T2 Relaxometry Approach

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Purpose

Propose a T2 relaxometry based multi-compartment model for brain tissues to quantify water fractions corresponding to myelin, axon and cells, and free fluids per voxel. Evaluate the proposed model on MS patients and observe temporal trends of the brain tissue microstructure for MS patients.

Method

The T2 space is modeled as a weighted mixture of signal contributions from the three compartments. Each compartment is described as a Gaussian probability density function in the T2 space.

Gaussian PDF depicting j-th compartment

Voxel signal at i-th echo → $s(t_i) = M_0 \sum_{j=1}^{3} w_j \int_{T_2} f_j(T_2; \mu_j, \sigma_j)\, EPG(T_2, \Delta TE, i, T_1, B_1)\, dT_2$

Field inhomogeneity

TurboSE sequence data suffer from the effect of stimulated echoes[1]. The echo curves for such sequences can be computed using Extended Phase Graph (EPG) algorithm [2].

Cost function optimized: $\min_{\boldsymbol{c},\boldsymbol{B_1}} \|\boldsymbol{Y} - \boldsymbol{S}\|_2^2 = \min_{\boldsymbol{c},\boldsymbol{B_1}} \sum_{i=1}^{n_{echoes}} \left(y_i - \sum_{j=1}^{3} c_j \int_{T_2} f_j(T_2; \mu_j, \sigma_j)\, EPG(T_2, \Delta TE, i, T_1, B_1)\, dT_2 \right)^2$

Observed signal; $M_0 \times w_j$

Values of $\{\mu_j, \sigma_j\}$ are chosen in accordance with information available from histology studies [3].
Since EPG does not have a closed form solution for its gradient along $\boldsymbol{B_1}$ [2], it is computed by a gradient free optimizer (BOBYQA [4]). $\boldsymbol{c}$ is computed by NNLS optimization. Optimization for $\boldsymbol{c}$ and $\boldsymbol{B_1}$ is performed alternatively until convergence is obtained in the desired error limit.

Results

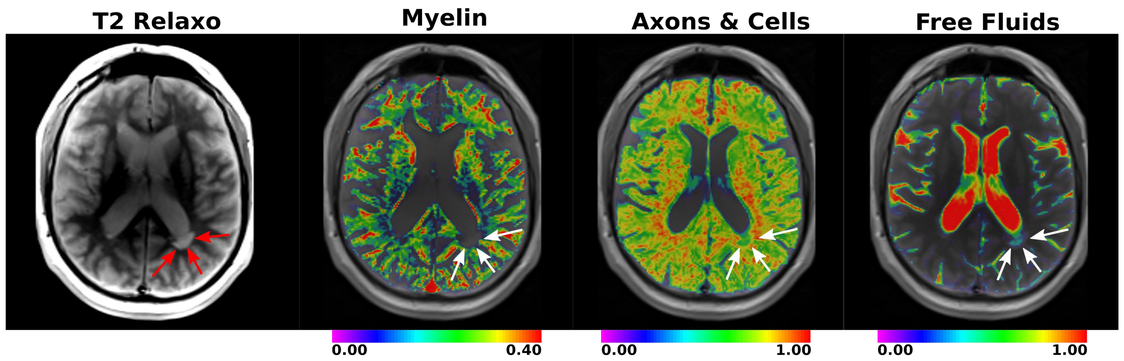


Figure 1: A Case of MS patient with a lesion around the ventricle. The estimated water fraction values of the compartments show lack of myelin presence in the lesion accompanied by axonal loss and accumulation of fluid. These are in accordance with the observations found in the literature on the pathology of MS lesions [5].

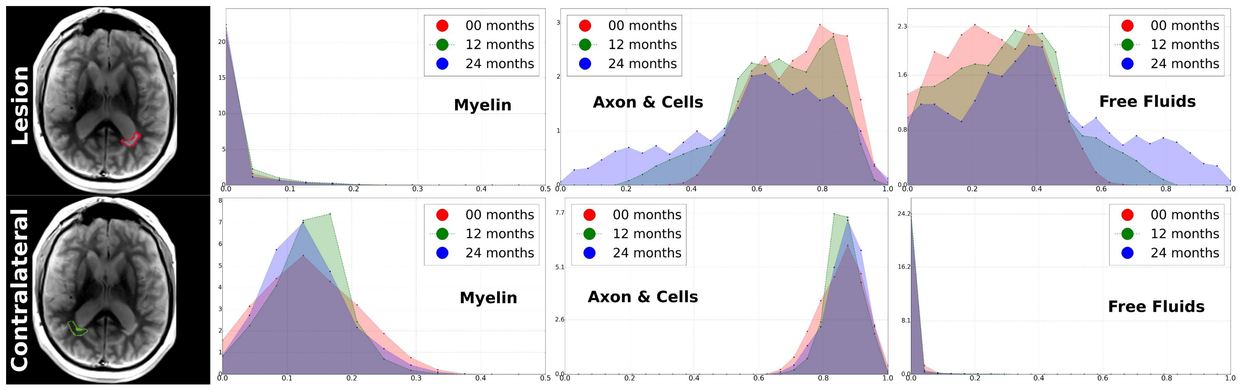
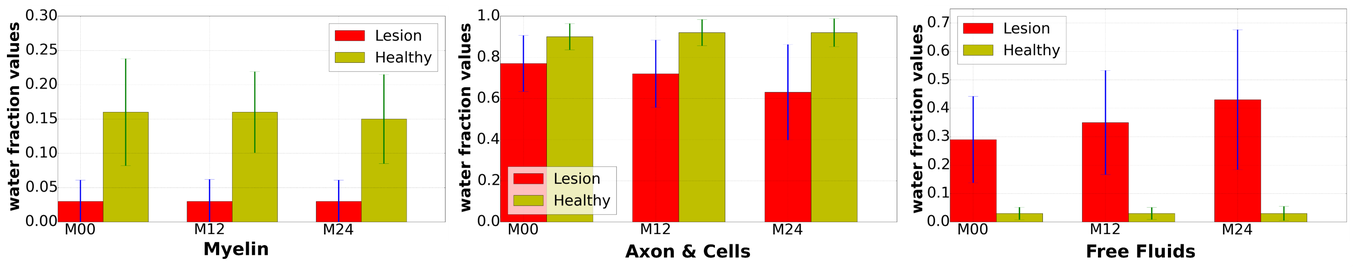


Figure 2: Comparison of the evolution of the distribution of the estimated water fraction values for the three compartments between a lesion ROI (top) and its contralateral healthy brain tissue ROI (bottom).

Figure 3: The lesion ROI water fraction value statistics exhibit the lack of myelin presence accompanied by an increasing fluid accumulation and continual axonal damage over the period of 24 months. The contralateral healthy ROI maintains healthy myelin and axonal water fraction values and show absence of any fluid accumulation.



Conclusion

The proposed T2 relaxometry multi-compartment model provides quantitative insights into the microstructure of brain tissues.
The observations of the experiments on patient data confirm those of existing literature [3, 5].

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