White matter characterization by massively multidimensional diffusion-correlation MRI

Omar Narvaez[1], Leo Svenningsson[2], Maxime Yon[2], Daniel Topgaard[2], and Alejandra Sierra[1]

[1]A. I. Virtanen Institute for Molecular Sciences, University of Eastern Finland, Kuopio, Finland
[2]Department of Chemistry, Lund University, Lund, Sweden

UNIVERSITY OF EASTERN FINLAND

LUND UNIVERSITY

Introduction

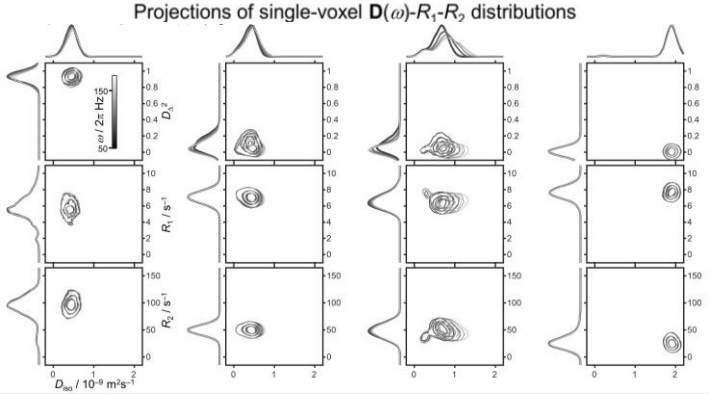
UNIVERSITY OF EASTERN FINLAND

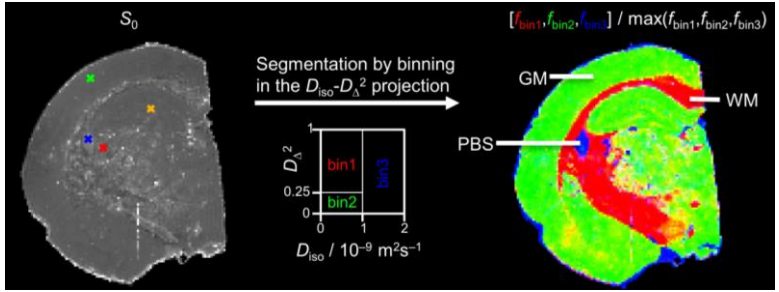
Massively multidimensional diffusion-correlation MRI uses free gradient waveforms to obtain nonparametric $\boldsymbol{D}(\omega)$-$\boldsymbol{R}_1$-$\boldsymbol{R}_2$-distributions[1].

- Squared normalized anisotropy - $\boldsymbol{D}_\Delta^2$
- Isotropic diffusivity - $\boldsymbol{D}_{iso}$
- Relaxation rates $\boldsymbol{R}_1$ and $\boldsymbol{R}_2$

To visualize the tissue fractions from the obtained $\boldsymbol{D}(\omega)$-$\boldsymbol{R}_1$-$\boldsymbol{R}_2$-distributions, a set of arbitrary "bins" limits are selected on the $\boldsymbol{D}_\Delta^2$ and $\boldsymbol{D}_{iso}$ plane.

To expand the within-tissue classification to not only in the 2D $\boldsymbol{D}_\Delta^2$ and $\boldsymbol{D}_{iso}$ plane, here we use the unsupervised k-means clustering method including the information of $\boldsymbol{D}_\Delta^2$, $\boldsymbol{D}_{iso}$, $\boldsymbol{R}_1$ and $\boldsymbol{R}_2$ to characterize the components in white matter.





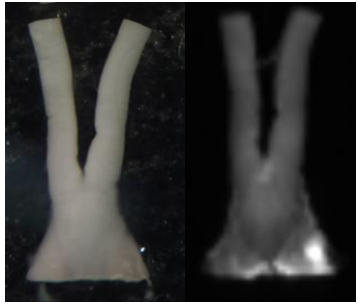
Methods

UNIVERSITY OF EASTERN FINLAND

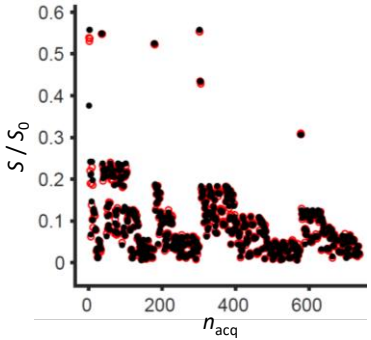
- 5 fixed rat brains with 4% paraformaldehyde (PFA).
- Both optic nerves were removed from each brain

Data acquisition and processing

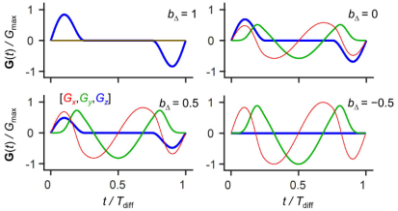
- Bruker Avance-III HD 11.7 T, MIC-5 probe 3 T/m
- Each scan consisted of 737 images using free gradient waveforms[4] varying b-value, b_Δ, (θ,ϕ), $\omega_{cent}/2\pi$, τ_R, and τ_E. The total scan time was ~20 hours.
- Images were denoised[5] and the Monte Carlo inversion algorithm was applied to obtain the nonparametric distributions[6]
- The mean distributions $E[D_\Delta^2]$, $E[D_{iso}]$, $E[R_1]$ and $E[R_2]$ across the 10 optic nerves were calculated for k-means clustering



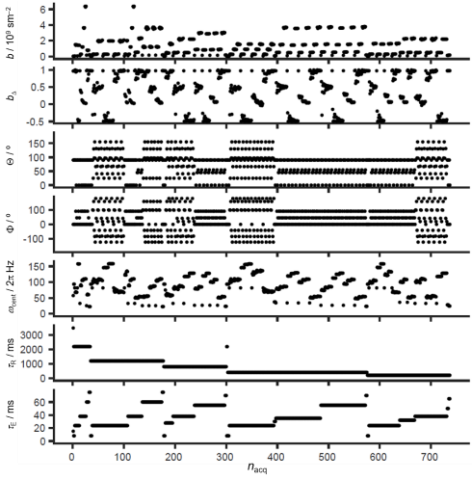
Optic nerves



b(ω)- τ_R - τ_E encoded signal



Gradient waveforms



Acquisition scheme

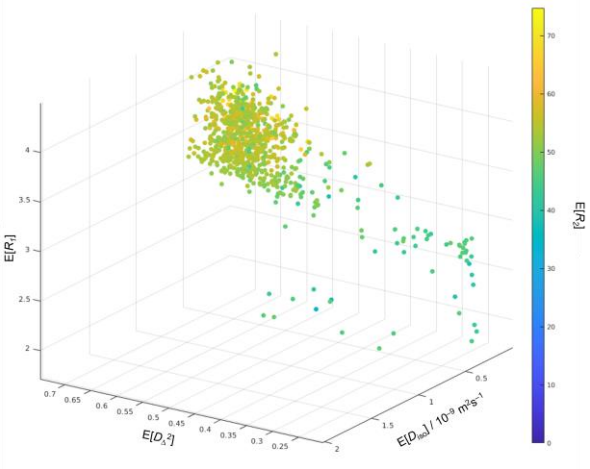
Results

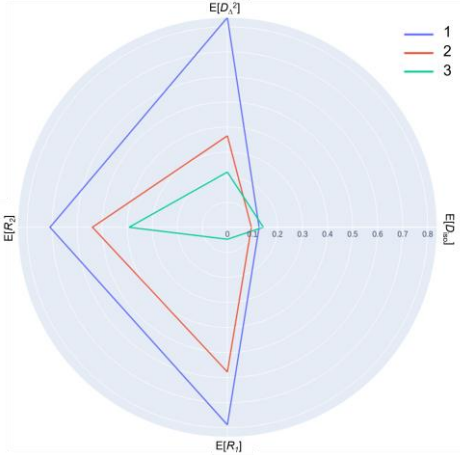
UNIVERSITY OF EASTERN FINLAND

In the 3D scatter plot can be observed that most part of the distribution is localized in high E[D_Δ^2], as expected for white matter.

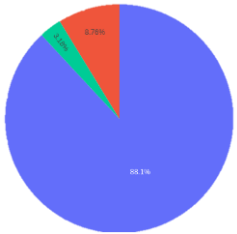
The resulted clusters in white matter shows that group 1 has the biggest contribution from E[D_Δ^2], E[R_1] and E[R_2]; group 2 shows a significant reduction of E[D_Δ^2], as well of E[R_1] and E[R_2]; and cluster 3 has the smallest contribution of E[D_Δ^2] and almost no contribution of E[R_1].

The cluster 1 is conformed by 88% percent of the data, cluster 2 by ~9% and cluster 3 by 3%. Each cluster might be related to the different elements in white matter.





3D scatter plot with the averaged distribution of E[D_Δ^2], E[D_{iso}] and E[R_1] (on the axes) and E[R_2] (as the color-code).



Conclusion

Our results show the potential of massively multidimensional diffusion-relaxation correlation acquisitions to disentangle the per voxel microstructure information of white matter. Furthermore, the characterization of the clusters by diffusivities, anisotropy, and relaxation rates of white matter would allow a better understanding of the subtle changes during pathologies.

Acknowledgments

We thank Maarit Pulkkinen for her assistance in animal and tissue handling.

We thank the Academy of Finland, Erkko Foundation, and the Doctoral Programme of Molecular Medicine (DPMM) from UEF for the funding support.

UNIVERSITY OF EASTERN FINLAND

References

[1] Narvaez *et al.*, 2022. doi: 10.3389/fphy.2021.793966

[2] Pierpaoli *et al.*, 1996. doi:10.1148/radiology.201.3.8939209

[3] Gelman *et al.*, 2001. Magn. Reson. Med.

[4] Yon *et al.*, 2020. NMR Biomed. doi:10.1002/nbm.4355

[5] Cordero-Grande *et al.*, 2019. Neuroimage. doi:10.1016/j.neuroimage.2019.06.039

[6] Nilsson *et al.*, 2018. In: Proceedings International Society Of Magnetic Resonance In Medicine