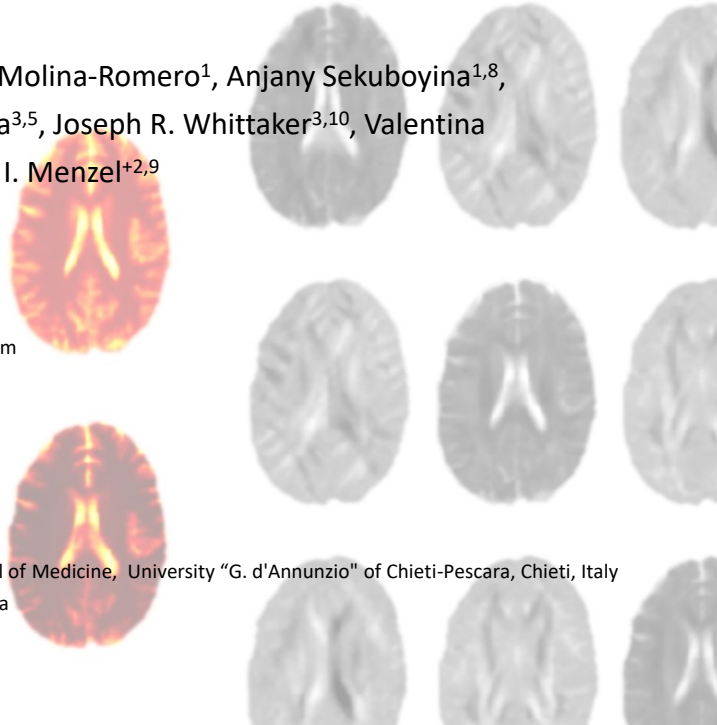
Deep learning-based parameter mapping for joint relaxation and diffusion tensor MR Fingerprinting

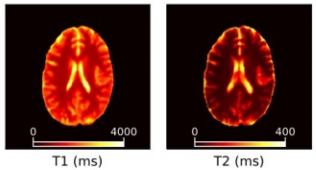
Carolin M. Pirkl[*1,2], Pedro A. Gómez[*1], Ilona Lipp[3,4,5], Guido Buonincontri[6,7], Miguel Molina-Romero[1], Anjany Sekuboyina[1,8], Diana Waldmannstetter[1], Jonathan Dannenberg[2,9], Sebastian Endt[1,2], Alberto Merola[3,5], Joseph R. Whittaker[3,10], Valentina Tomassini[3,4,11], Michela Tosetti[6,7], Derek K. Jones[3,12], Bjoern H. Menze[+1,13,14], Marion I. Menzel[+2,9]

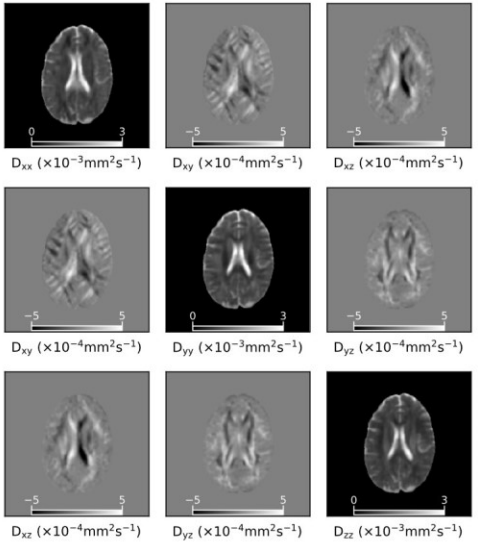
[1]Department of Informatics, Technical University of Munich, Garching, Germany
[2]GE Healthcare, Munich, Germany
[3]Cardiff University Brain Research Imaging Centre (CUBRIC), Cardiff University School of Psychology, Cardiff, United Kingdom
[4]Institute of Psychological Medicine and Clinical Neurosciences, Cardiff University School of Medicine, Cardiff, United Kingdom
[5]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany
[6]Fondazione Imago7, Pisa, Italy
[7]IRCCS Fondazione Stella Maris, Pisa, Italy
[8]Department of Neuroradiology, Klinikum rechts der Isar, Munich, Germany
[9]Department of Physics, Technical University of Munich, Garching, Germany
[10]Cardiff University School of Physics and Astronomy, Cardiff, United Kingdom
[11]Institute for Advanced Biomedical Technologies (ITAB), Department of Neurosciences, Imaging and Clinical Sciences, School of Medicine, University “G. d'Annunzio" of Chieti-Pescara, Chieti, Italy
[12]Mary McKillop Institute for Health Research, Faculty of Health Sciences, Australian Catholic University, Melbourne, Australia
[13]Center for Translational Cancer Research, Munich, Germany
[14]Munich School of BioEngineering, Garching, Germany



MR Fingerprinting (MRF)

Ma et al. *Nature* (2013)
Jiang et al. *Magn Reson Med* (2015)





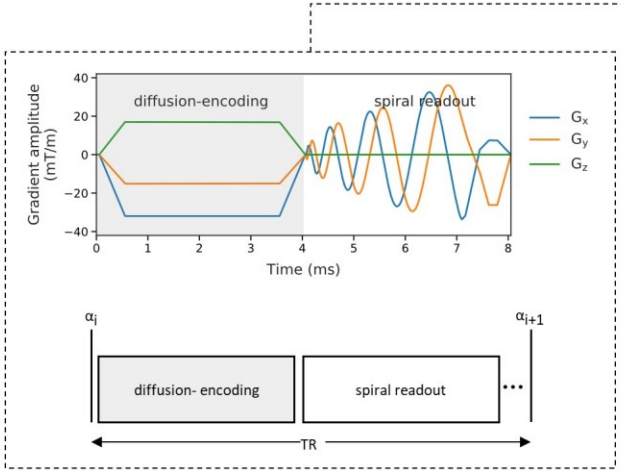
Diffusion-weighted MRF

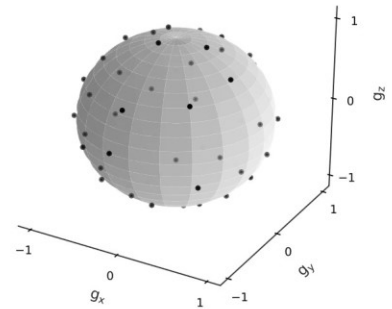
Jiang et al. *ISMRM* (2014, 2016, 2017)
Cohen et al. *ISMRM* (2018)
Rieger et al. *ISMRM* (2018)

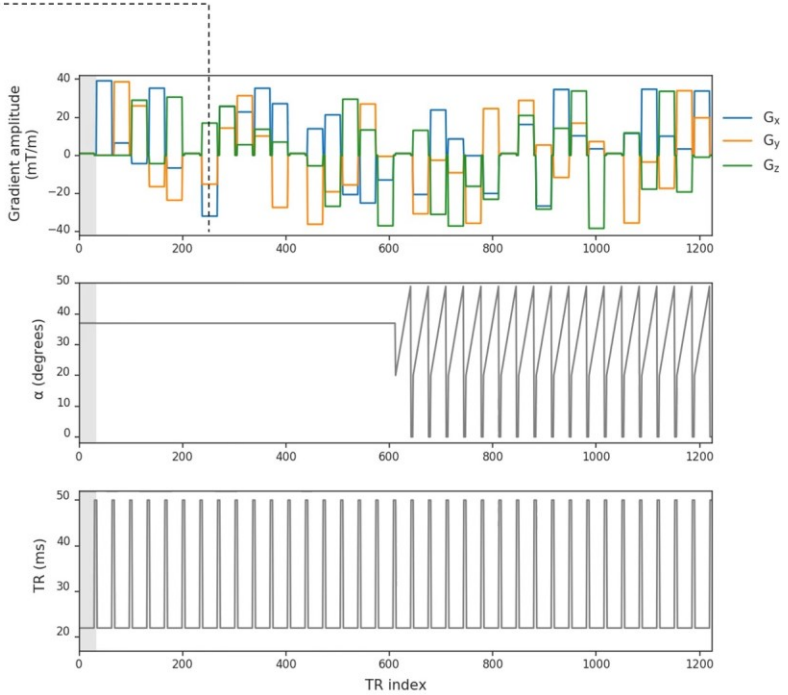
Deep learning-based parameter mapping for joint relaxation and diffusion tensor MR Fingerprinting

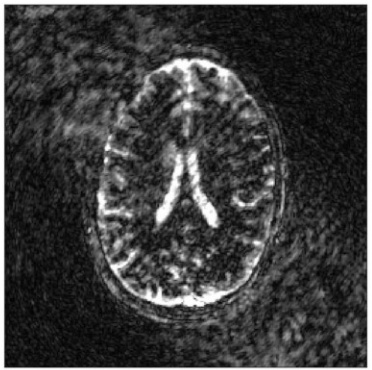
Pirkl, Gómez et al. *MIDL* (2020)

Methods | Diffusion-sensitized MRF sequence









Acquisition parameters

- 1.2×1.2×5 mm^3 resolution
- 22.5×22.5 cm^2 FOV
- Variable density spiral sampling (34 interleaves)
- 30 diffusion encoding directions
- TI = 18ms, TE = 6ms
- 32s / slice acquisition time

Sliding window reconstruction

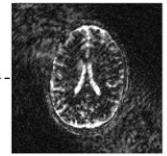
- Window size = 34
- Window stride = 34

McNab & Miller *NMR Biomed* (2010), Bieri et al. *Magn Reson Med* (2012), Gómez et al. *ISMRM* (2017)

Methods | CNN-based parameter mapping

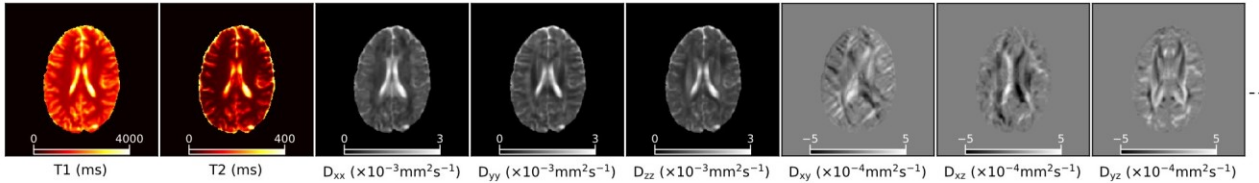
MRF image-series $\boldsymbol{x}$

$\boldsymbol{x} \in \mathbb{R}^{256\times256\times T}$,
$T = 36$ temporal channels



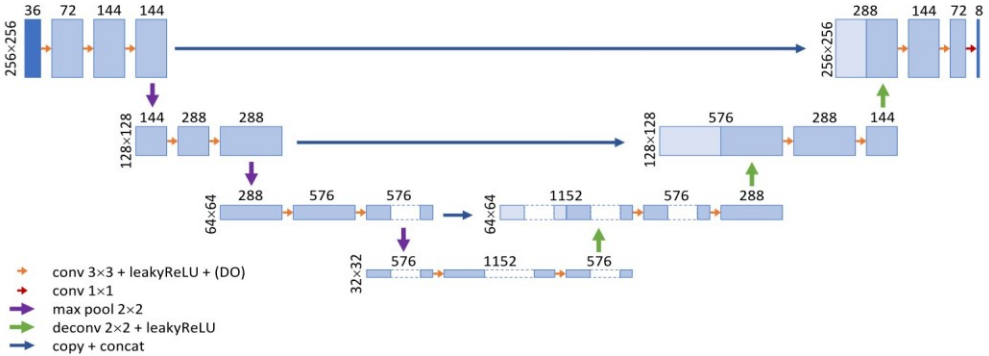
Quantitative relaxation and diffusion tensor reference maps $\boldsymbol{y}$

$\boldsymbol{y} \in \mathbb{R}^{256\times256\times Q}$,
$Q = 8$ quantitative channels



$$\boldsymbol{x}' = \frac{\boldsymbol{x} - \min(\boldsymbol{x})}{\max(\boldsymbol{x}) - \min(\boldsymbol{x})}$$

$$\boldsymbol{y}'_q = \frac{\boldsymbol{y}_q}{\max(|q_{min}|, |q_{max}|)}$$



Dataset

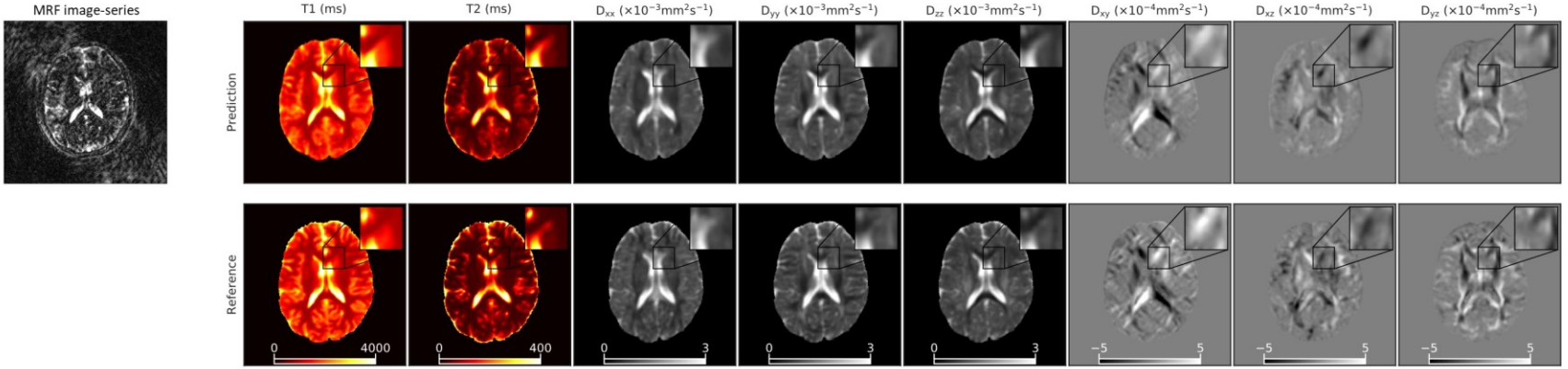
- 11 MS patients, 9 healthy volunteers
- 8-12 slices / subject

Experimental setup + CNN training

- 10-fold cross validation
- L1 loss
- Learning rate = 1e-4
- Dropout rate = 0.25
- Batch size = 5
- 400 epochs

Ronneberger et al. *MICCAI* (2015), Deoni. *JMRI* (2007), Deoni et al. *Magn Reson Med* (2003)

Results | Qualitative evaluation



Relaxation and diffusion tensor maps

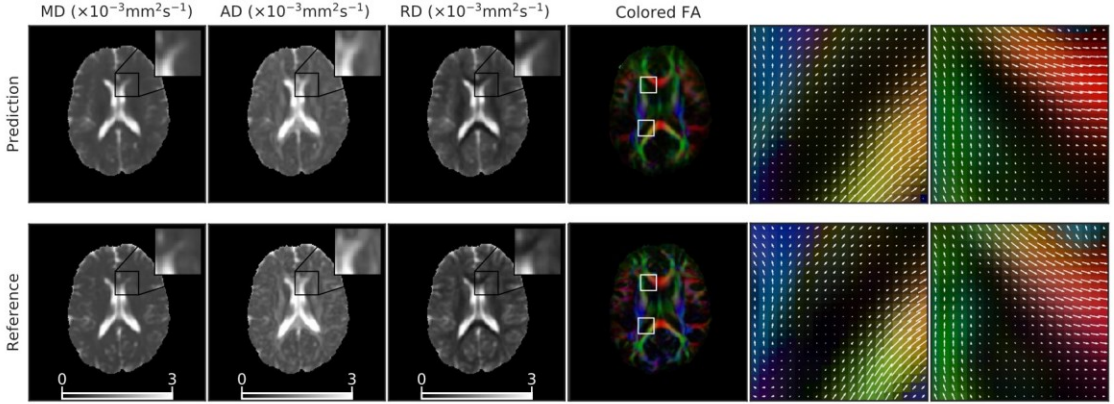
- High consistency between CNN prediction and state-of-the-art reference
- CNN reliably reconstructs relaxation and orientational diffusion information

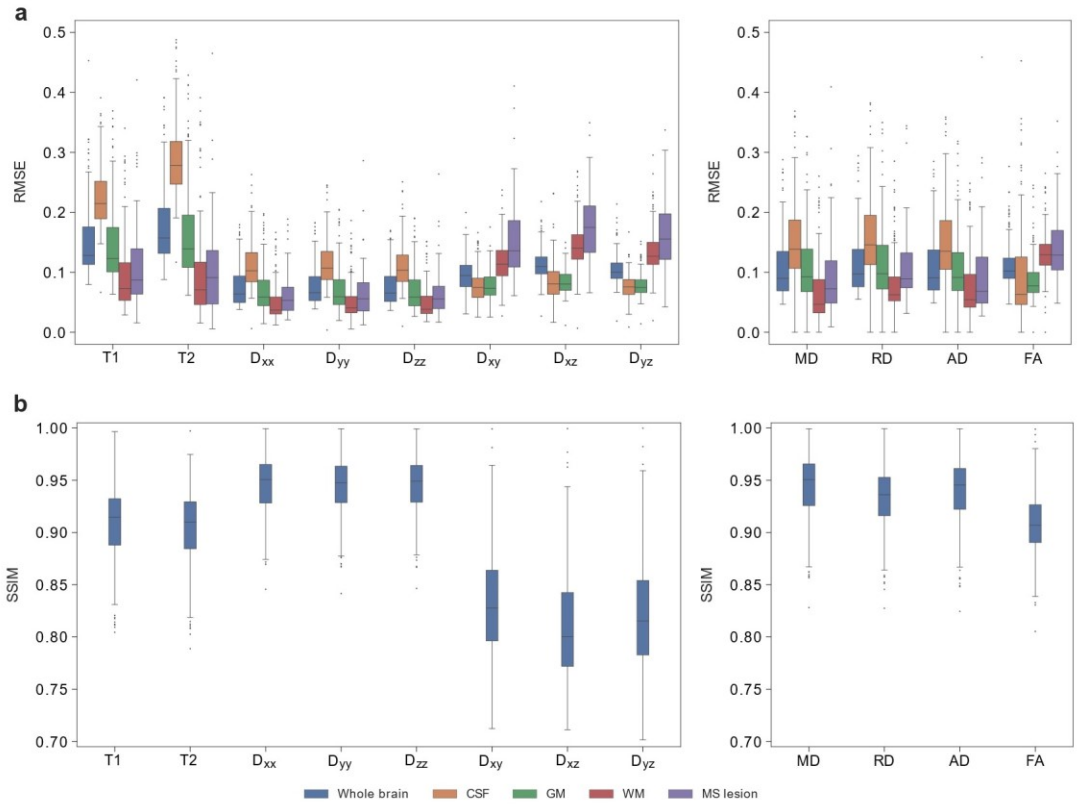
Scalar diffusion metrics

Good agreement with EPI-DTI reference

Colored FA maps + primary diffusion eigenvectors

Characteristic fiber structure in WM is captured





Quantitative evaluation substantiates qualitative findings

- Reliably reconstruction of relaxation and orientational diffusion information, also in regions of diagnostic importance (MS lesions)
  → Generalization capability
- Comparable reconstruction performance for T1 and T2 with respect to DESPOT1/2 methods
- Better agreement with EPI-DTI reference for diagonal diffusion tensor elements (D_{xx}, D_{yy}, D_{zz}) than off-diagonal elements (D_{xy}, D_{xz}, D_{yz})

Relaxation and diffusion-sensitized MRF sequence

CNN-based multivariate regression

- ✓ Relax MR acquisition requirements
- ✓ Efficiently encode:
  - T1 and T2 relaxation times
  - Orientational diffusion information
- ✓ Bypass conventional dictionary matching

Thank you!

Outlook: Improve on our baseline

- More advanced deep learning approaches
- More efficient, motion-robust diffusion encoding scheme

Major challenge: Severe head motion

→ Prospective and retrospective motion correction approaches

→ Increase motion robustness of sequence design