Initial assessment of the effect of B_0 on quantitative T_2 and diffusion-MRI

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INTRODUCTION:

Quantitative MRI is important for developing biomarkers for the early detection and monitoring of neurological diseases and evaluating drug treatments. Quantitative MRI is promoted by the development of biophysical models of brain tissue. While such models were initially developed and tested on MRI scanners with routine clinical field strengths (1.5T – 3T), their utility and interpretation remains challenging at lower (0.55T) or higher (7T) field strength. Understanding the effect of magnetic field strength (B_0) on quantitative T_2-relaxometry and diffusion-weighted MRI metrics is of interest to correctly interpret quantitative model measurements in relation to the underlying microstructure. This work aims to test the feasibility of performing quantitative MRI on a wide range of field strengths and to study the effect of B_0 on quantitative T_2 and diffusion MRI.

METHODS:

- 1 Healthy subject scanned at 0.55T, 1.5T, 3T, and 7T
- Data acquisition:
  - MP-RAGE
  - DWI: 2D-EPI; 2 mm isotropic resolution; min TR = 5.5 s – 6.8 s; TE = 73 ms; b = 0/500/1000 s/mm^2
  - T_2 mapping: 2D multi-echo CPMG; 2 mm isotropic resolution
    - Shortest echo spacing: 8.1/6/7.3/7.6 ms for 0.5T/1.5T/3T/7T
    - Further echo spacing (all field strengths): 10/15/20 ms
- Data Processing:
  - Diffusion MRI: Denoising; Gibbs ringing mitigation; eddy current correction; EPI distortion correction (Benjamin Ades-Aron et al. 2018)
  - Image registration to the 3T MP-RAGE using ANTs (rigid transformation)
- Data Analysis:
  - T_2 Maps: EMC-Dictionary matching approach (Ben-Elizier at al. 2015)
  - Diffusion tensor imaging, with derived Fractional Anisotropy and Mean Diffusivity maps ROI analysis using
    - JHU atlas segmentation using diffeomorphic registration using ANTs
    - Freesurfer recon-all
    - 57 ROIs in WM, cortical GM, and subcortical structures

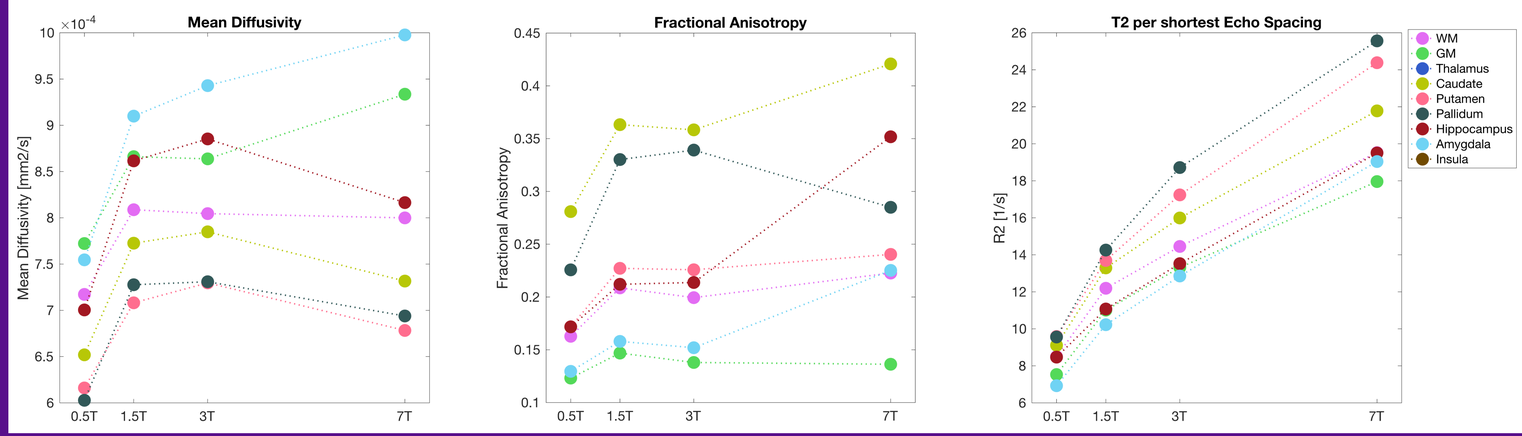

Fig. 2: Comparison of quantitative diffusion metrics and $R_2 = 1/T_2$ as a function of B_0. The markers represent the median in respective ROI. R_2 increases as a function of B_0 as described in the literature (Y. Gussin et al. 2000). Reduction in MD at 0.55T and 7T are likely caused by Rician noise and multiple tissue compartments.

FIGURE 4

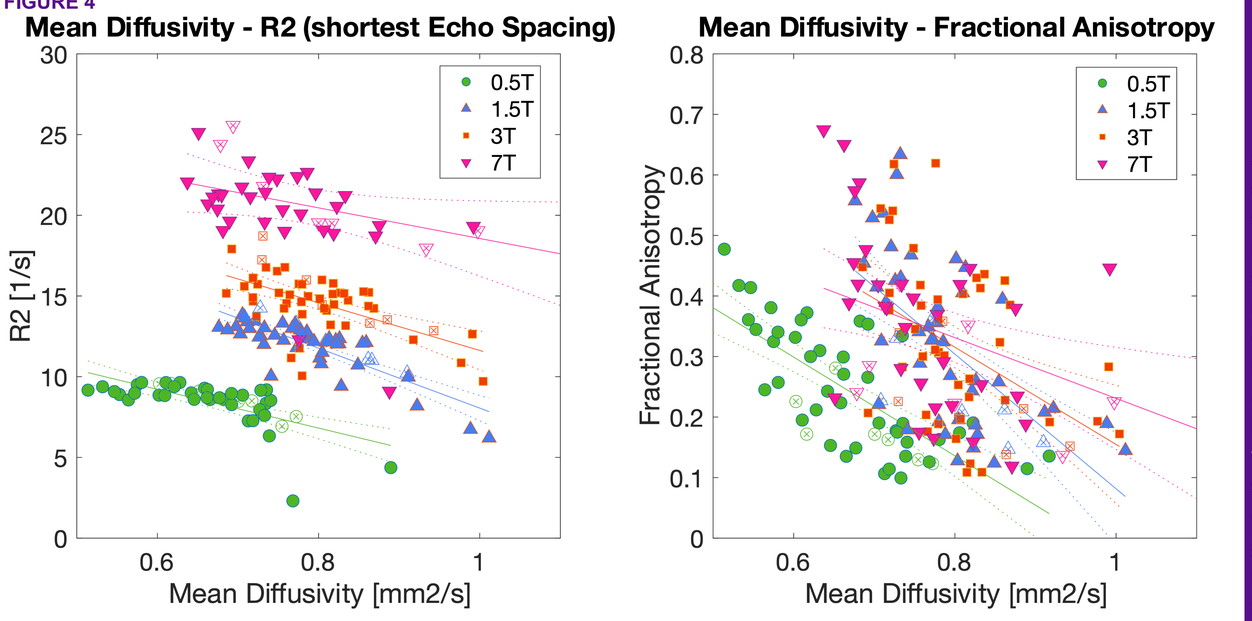

Fig. 4: Scatter plots between Mean Diffusivity and R_2, and Mean Diffusivity and Fractional Anisotropy across the four different field strengths. Each dot represents the median of the quantitative metrics for each ROI (filled marker: all individual WM ROIs (JHU atlas); open marker: whole WM, whole GM, and subcortical ROIs (FreeSurfer). Each group displays its respective linear regression model.

FIGURE 1

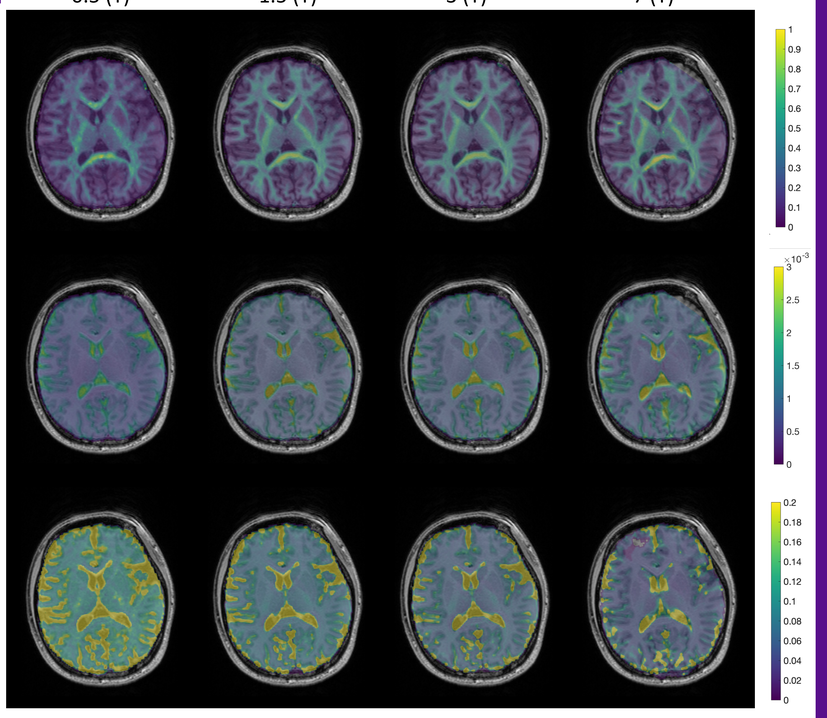

Fig. 1: Quantitative metrics overlaid on the reference MP-RAGE image for different field strengths. The residual misalignment of the T_2 map at 7T is due to gaps between the acquired slices.

FIGURE 3

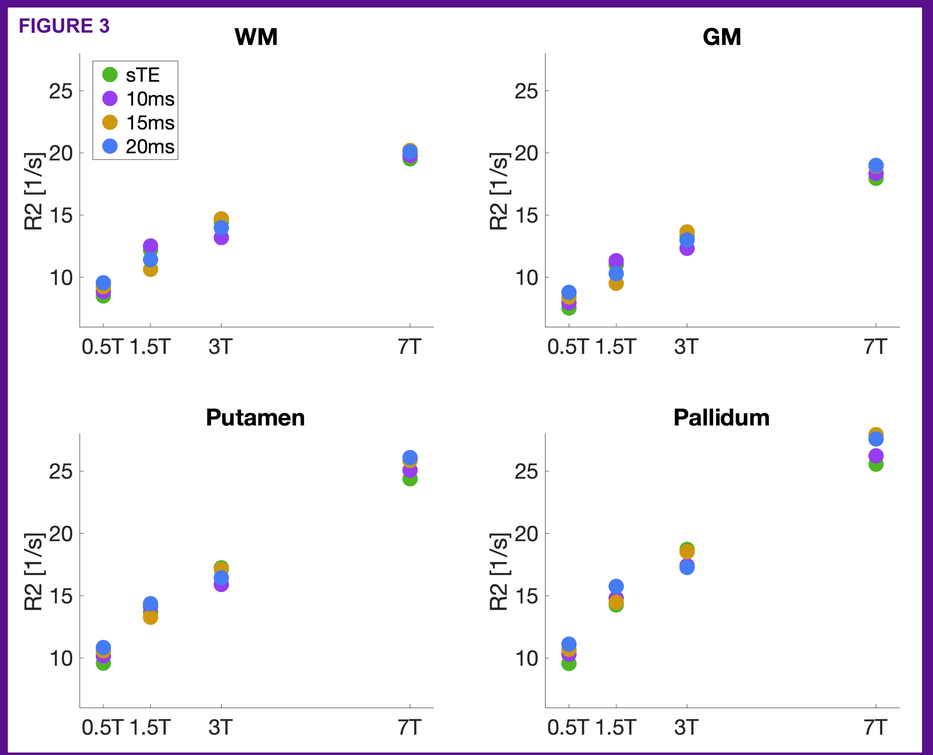

Fig. 3: Comparison of R_2 as a function of the echo spacing and B_0. As anticipated (Y. Gussin et al. 2000), the echo spacing has only a minimal impact on R_2. As a function of B_0, we observe an approximately linear increase of R_2.

DISCUSSION:

- Effect of field strength on R_2: Linear trend in line with the observations made by Y. Gussin et al. 2000.
- No clear effect influence of the echo spacing on R_2 (in line with Y. Gussin et al. 2000)
- Reduced MD and R_2 at low field (0.55T). At low field strength, we are challenged by low signal-to-noise ratios. We hypothesize that the reduced MD at low field is a result of the Rician bias that will require dedicated correction.
- Reduced MD and increased FA at high field (7T). In agreement with previous studies, we observe a reduced MD and increased FA in white matter ROIs at 7T, compared to 1.5 and 3T. We hypothesize that this result is a result of the presence of multiple tissue compartments in the WM, including intra- and extra-axonal spaces. The B_0 dependency of compartmental T_2 relaxation times lowers the relative signal contribution of extra-axonal signals, thereby promoting the more restricted and coherent intra-axonal signal (Zahn et al. 2013, Kleban et al. 2020).
- Reduced correlation between R_2 and MD at high field. We observe an increased variability in R_2 values across different WM regions at 7T, compared to lower field strengths. While additional data is required to understand this observation, a potential explanation for the increased variability at high fields could be a more pronounced dependence of R_2 on the orientation of the fiber tracts due to susceptibility effects.

FUTURE WORK:

- Acquire more data to test the hypotheses.
- Evaluate the hypothesis at ultra-low field.

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REFERENCES:

Benjamin Ades-Aron et al. 2018, Ben-Elizier at al. 2015, Y. Gussin et al. 2000, Zahn et al. 2013, Kleban et al. 2020.