The effects of b-shell selection on estimation of multi-compartment microscopic diffusion parameters

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Abstract: Diffusion MRI sampling, particularly the selection of multiple b-shells is extremely important for the advanced multi-compartment model fitting. Inappropriate selection of these b-shell combination could bias the estimated intrinsic tissue specific intra neurite volume fraction (INVF) and intrinsic diffusivity (ID) maps.

In this study NODDI and SMT maps were calculated for multiple b-shell combinations to test the sensitivity of these models to the selection of b-shells

Motivation

Diffusion biophysical models like NODDI and SMT provides unique information about fine architecture of neuronal tissues and changes associated with various physiological and pathological states. Intrinsic tissue specific parameter maps estimated by these models are sensitive to diagnostically relevant tissue specific features in the range of few micrometers like cell size, shape and density.

These models use complex fitting routines to fit the observed diffusion signal into different tissue compartments and require multiple b-shell sampling to stabilize the solution numerically and provides better results. But selection of these multiple b-shells (combination of low and high b-shell), is extremely important to estimate the parameters precisely and with more consistency, without any bias in estimated INVF and ID.

Methods

Diffusion-weighted images (3 in-vivo mouse brain) were acquired at 9.4T Bruker scanner using a SE-EPI sequence (5 b=0, and b=1,2,3,4,5,6 ms/μm^2 with 30 directions each using gradient duration/separation of 5/12.5 ms; TE/TR=25/2000ms, spatial resolution=125X125X500μm^3, 4 shots).

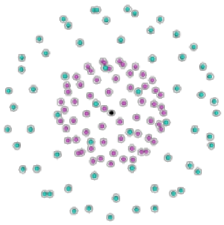
The diffusion weighted images were denoised, and corrected for eddy current and motion distortions using FSL and MATLAB tools. To find the overall trends in the INVF and ID for different models we segmented White matter tissue ROI as the voxels with linearity[4] greater than 0.3, estimated from the diffusion tensor fit.

NODDI and SMT models were applied to the acquired datasets and respective maps were estimated using the available software tools.

Combination of b-shells [ms/μm^2]:

2 shells: P1 = 1 & 2, P2 = 1 & 3, P3 = 1 & 4, P4 = 1 & 5, P5 = 1 & 6, P6 = 2 & 3, P7 = 2 & 4, P8 = 2 & 5, P9 = 2 & 6, P10 = 3 & 4, P11 = 3 & 5, P12 = 3 & 6.

3 shells: P13 = 1& 2 & 3, P14 = 2 & 3 & 4, P15 = 3 & 4 & 5.



Multi-shell acquisition

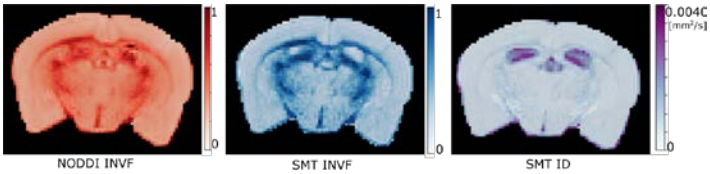


Fig.1. Depicts the NODDI and SMT calculated intra-neurite volume fraction (INVF) and SMT calculated intrinsic diffusivity (ID) maps.

Results

We observed the strong dependency of b-shell selection on estimated microscopic parameters for both white matter and grey

matter tissues (Fig.2). These overall INVF parameter values estimated by NODDI were higher than the values estimated by SMT at each combination. NODDI assumes a single and fixed ID value (0.0017mm^2/s), whereas SMT estimates the ID directly from the data, but we observed that these estimated ID values depends upon selection of b-shells, and it may influence the estimation of intra and extra-neurite volume fractions. NODDI and SMT calculated INVF along different b-shell protocols reports high variation with respect to the full data set (Fig.3).

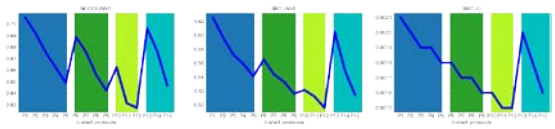


Fig.2. Estimated NODDI and SMT, INVF and ID parameter values for different b-shell combinations.

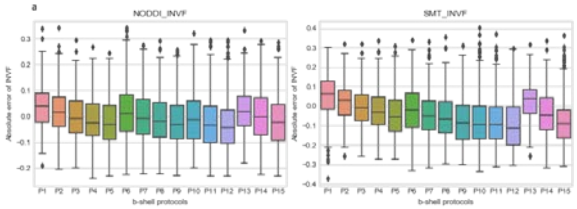


Fig.3. Absolute estimation error in the NODDI and SMT calculated INVF for different b-shell combinations with respect to the full data set.

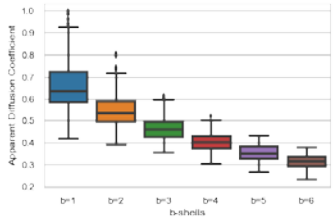


Fig.4. Plot of the ADC in WM against b-shells, clearly reflecting that at higher b-values, the plot gets curved and the ADC decreases with b-values.

Discussion

Our in vivo observation suggests that selection of b-shells could cause bias in the estimation of model parameters rather than giving the precise and accurate information about actual intra and extra-neurite volume fractions. Difference between b-values must be higher for statistically better performance of these models, but current study demonstrates that, large difference between b-shells may estimate lower parameter values. In summary the quantitative estimates are model-dependent and b-shell dependent, exhibiting biases and limitations related to the model assumptions and acquisition protocol.

Summary

Selection of b-shells turned out to be extremely important for the estimated INVF and ID, most likely caused by the multi-exponential decay of the diffusion signal (particularly at high b-values).

References

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