Abstract 664

Study of Diffusion Kurtosis Imaging parameters using Monte Carlo simulations

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Authors: D.N. Sousa, H.A. Ferreira; Lisboa/PT

Purpose/Introduction

Diffusion Kurtosis Imaging (DKI) is a non-invasive technique that quantifies the non-gaussianity of water diffusion in vivo via the kurtosis (K) parameter, being sensitive to the heterogeneity of tissues[1]. Multiple compartment models are idealized models of tissues' structure which are widely used to represent intracellular and extracellular spaces [1]. To better understand the sensitivity of the diffusion kurtosis model to microstructural changes, Monte Carlo simulations (MCS) were done based on computationally simulated tissues. Additionally, it was investigated if simulations could provide information to complement multiple compartment models.

Subjects and Methods

Experiment 1: A two-compartment model (2CM) [1] without water exchange was used to analytically compute diffusion considering intracellular volume fractions (V) between 0.1 and 0.8 in 10 steps. Intracellular and extracellular coefficients of free diffusion were set to (1.0 and 2.5)x10^{-3} mm^2/s, respectively.

Experiment 2: MCS of a random walk in a 2-D space with 0.4x0.4mm^2 was implemented in nodejs over the CrowdProcess platform [2], based on the methods used in [3]. The intracellular volume fraction was varied between 0.1 and 0.8 in 10 steps, and cell configurations were designed randomly with a gamma distribution of the cell radii, having a mean of 5, 10 and 15 μm in each case and a constant ratio (standard deviation)/mean of 0.7. 1,000,000 dimensionless random walkers with a time-step of 2.5x10^{-5} s were placed in these cell environments and performed a walk of 0.0263 s. Intracellular and extracellular diffusion coefficients were set to the same values of experiment 1. Membrane permeability was not considered.

Experiment 3: Experiment 2 was repeated with membrane permeability set to 0.01 mm/s.

Results

The figures below show the K parameter vs V for the 2CM (Kc) and for the MCS (K1-3), considering or not cell membrane permeability. It can be observed that the 2CM underestimates K values regarding MCS, and that considering cell membrane permeability decreases K values.

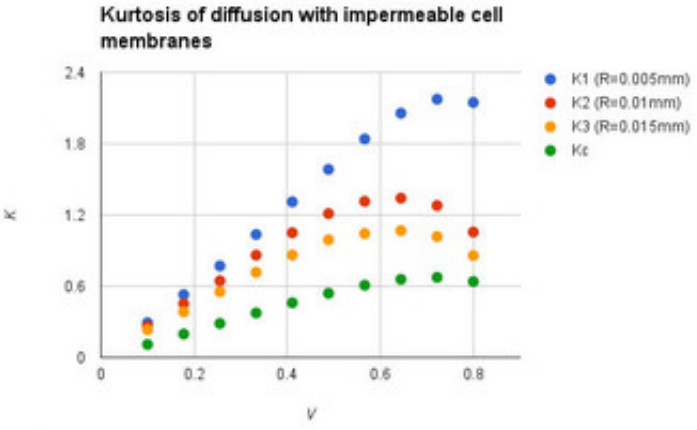

Fig. 1: Kurtosis computed from the two compartment model and measured from Monte-Carlo simulations in cell environments with mean cell radii 0.005 mm, 0.001 mm and 0.015 mm and no cell membrane permeability. V is the intracellular volume fraction.

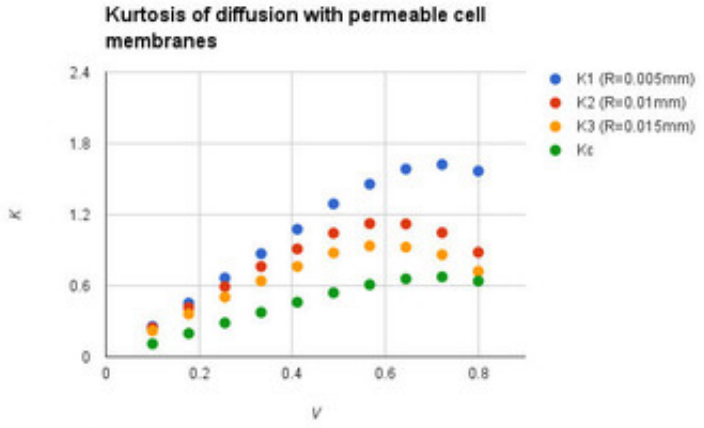

Fig. 2: Kurtosis computed from the two compartment model and measured from Monte-Carlo simulations in cell environments with mean cell radii 0.005 mm, 0.001 mm and 0.015 mm and cell membrane permeability of 0.01 mm/s. V is the intracellular volume fraction.

Discussion/Conclusion

The 2CM presently does not account for cell membranes neither membrane permeability. Therefore, MCS enable the study of diffusion processes in more complex cell environments, giving further insights about tissues' structure. MCS should thus be taken into account when interpreting DKI parameters.

References

- [1] Jensen JH, Helpern JA. MRI Quantification of Non-Gaussian Water Diffusion by Kurtosis Analysis. NMR Biomed. 2010; 23:698-710.
- [2] CrowdProcess:https://crowdprocess.com/overview [cited 2015 January].
- [3] Lee C-Y, Bennet KM, Debbins JP. Sensitivities of statistical distribution model and diffusion kurtosis model in varying microstructural environments: a Monte Carlo study. J Magn Reson. 230; 2013 19–26.

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