Assessment of Tissue Properties and T2 relaxation on ADC Measurements by Numerical Simulation of Water Diffusion

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Introduction

Since the initial observation of the drop in the apparent diffusion coefficient (ADC) following ischemic stroke, the biophysical mechanisms which effect ADC have been heavily discussed [1]. Analytic and numerical models have shown to be useful in analyzing diffusion-weighted MRI (DWMRI) results in terms of biophysical tissue properties and experimental parameters. Many possible mechanisms have been suggested to be important, most notably the intracellular volume fraction (IVF) and the diffusivity of water in the intracellular compartment. However, modeling to date has not critically assessed the effects of compartment specific T2 relaxation times on experimental DWMRI results. In this abstract, a numerical model of tissue water diffusion is used to assess the effect of IVF and intracellular diffusivity while allowing for independent intracellular and extracellular T2 relaxation times.

Methods

The numerical model uses a finite difference approximation to the diffusion equation with T2 relaxation. Tissue is modeled as 3D cubic cells surrounded by a permeable membrane and separated by extracellular space. The model employs an effective diffusion propagator (EP) [2] which includes the effect of T2. Within the short gradient pulse approximation, a Fourier relationship between the effective propagator and diffusion-related signal decay is used to obtain signal as a function of $q = \gamma G\delta/2\pi$, where G is the gradient strength in a Stejskal-Tanner diffusion experiment, δ is the duration of the gradient pulse. An ADC is calculated by performing a change of variables, $b=(2\pi q)^2\Delta$, where Δ is the time between diffusion gradients, and fitting the signal decay as a function of b to an exponential decay for b-values between 0 and 1.0 ms/μm^2. The model considers 7 tissue parameters: intracellular and extracellular diffusion coefficients (D_{int} and D_{ext}), intracellular and extracellular T2 relaxation rates ($T2_{int}$ and $T2_{ext}$), membrane permeability (P_{mem}), intracellular volume fraction (IVF), and cell size (L_{cell}). Unless indicated, simulations are run with the following parameters: D_{int} = 1.0 μm^2/ms, D_{ext} = 3.0 μm^2/ms, L_{cell} = 10 µm, P_{mem} = 0.01 µm/ms, IVF = 80%, $T2_{int}$ = 50 ms, $T2_{ext}$ = 150 ms and TE = 80 ms.

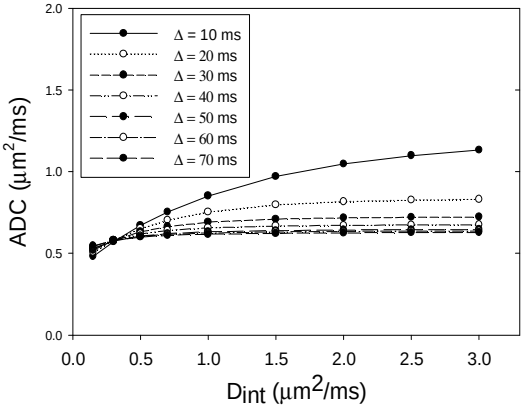

Fig 1: Calculated ADC as a function of D_{int}, at multiple diffusion times. Simulations show that the ADC is nearly independent of D_{int} at $\Delta > 20$ ms.

Results and Discussion

The effect of changes in D_{int} on calculated ADC is shown in Fig. 1. The model predicts that, except for very small diffusion times (Δ = 10 - 20 ms), the ADC is nearly independent of D_{int}. This independence is due to the restrictive effects of the cell membrane, i.e. much of the intracellular water has been restricted by the membrane, and therefore is not affected by changes in D_{int}. Similarly, ADC is plotted as a function of IVF in **Fig 2** at several values of $T2_{int}$, where T2 is homogenous in the model at $T2_{int}$ = 150 ms. Simulations show that the ADC generally increases as $T2_{int}$ decreases due to T2 filtering – decreasing $T2_{int}$ relative to $T2_{ext}$ more heavily weights towards water signal to the unrestricted extracellular compartment. However, the percent decrease in ADC due to cell swelling also increases as $T2_{int}$ is decreased. For instance, with homogenous T2 ($T2_{int}$ = $T2_{ext}$ = 150 ms), the ADC drops only 24% with an increase in IVF from 80% to 90%. However a similar decrease in IVF produces a decrease of 32% and 42% for $T2_{int}$ = 50ms and 25ms respectively.

Conclusion

The simulation presented in this abstract predicts a 30-50% decrease in ADC by increasing IVF from 80-90% when $T2_{int}$ is allowed to be shorter than $T2_{ext}$. Simulations also showed the ADC to be relatively independent of the intracellular diffusivity due to restriction of the cell Fig 1: Calculated ADC as a function of D_{int}, at multiple diffusion times. Simulations show that the ADC is nearly independent of D_{int} at $\Delta > 20$ ms. Therefore, if T2 relaxation times are smaller inside the cell compared to outside, the drop in ADC following ischemia may be sufficiently explained by an increase in the IVF.

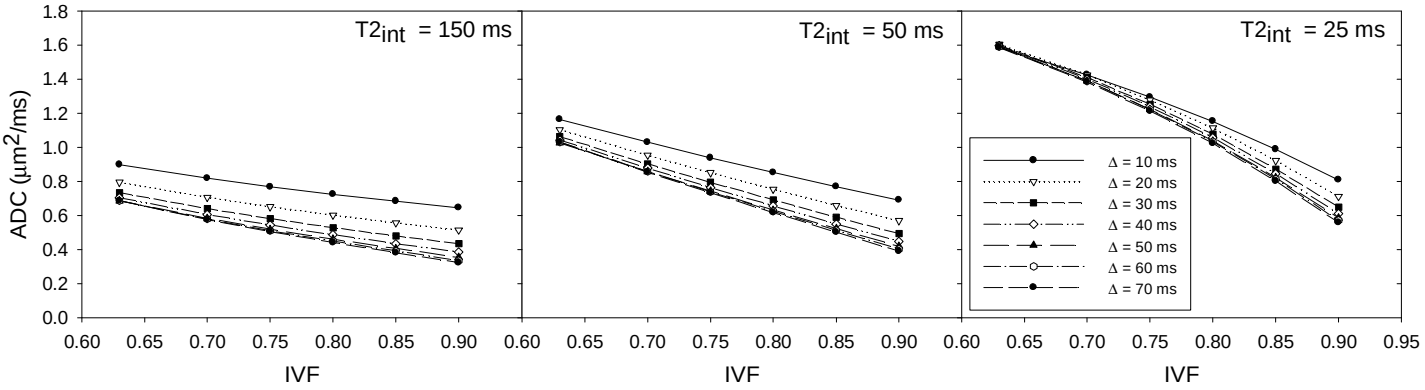

Fig 2: Calculated ADC as a function of IVF. Simulations show that the ADC decreases with IVF, which is more pronounced at low $T2_{int}$.

References

1. Moseley et al. MRM 1990, 14:330 2. Hagslatt et al. JMR 2003, 161:138

Acknowledgments

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