New Quantitative Indices for DWI of the Brain Tissue at High b-Values

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Introduction

Attenuation of the NMR water signal by molecular diffusion in brain tissue gives rise to valuable information regarding the early detection of stroke and the diagnostics of various neurological disorders. Visualization contrast in Diffusion Weighted Imaging (DWI) is generally based on the sensitivity of the molecular diffusion to the local geometrical and physiological environment [1, 2]. Conventional methods, however, address only the average characteristics of molecular propagation related to the lower range of the *b*-values. Recently, increasing efforts [3, 4] have been devoted to a *q*-space and a multiple-*b*-value analysis of the diffusion patterns in order to enhance information about diffusion mechanisms and the underlying microstructure. The aim of this work is to study the potential of the *in vivo* DWI in the extended range of *b*-values and to reconstruct maps of new quantitative indices.

Results and Discussions

In vivo diffusion studies were carried out with a 3T Siemens MAGNETOM Trio scanner. DW images were acquired using a double spin-echo EPI pulse sequence provided by manufacturer for 15 *b*-values (up to 7000 s mm^{-2}) and 6 directions of the diffusion gradient. The voxel size was $2\times2\times2$ mm^3. Nonlinear least-square fits were performed on a voxel-by-voxel basis for the following three models: a) $S(b)/S(0)=e^{-Db}$; b) $S(b)/S(0)=p_a e^{-D_a b}+(1-p_a)e^{-D_b b}$; c) $S(b)/S(0)=e^{-D_{app}b+K_{app}D_{app}^2 b^2/6}$.

Figure 1 demonstrates typical diffusion patterns averaged over 9 voxels in two representative ROIs indicated in Fig. 2a: *quasi*-Gaussian behaviour in ROI 1 and pronounced deviations accompanied by a strong anisotropy in ROI 2. It should be noted that D, D_a, D_b are not to be confused with the intrinsic molecular diffusivities of water molecules and will be referred to as "reduced diffusivities" (analogous to the ADC). The slow component of attenuation is frequently attributed to the intra-axonal water [3]. In this case, D_b is related to the mean squared displacement $\langle x^2 \rangle$ during the observation time, *t,* resulting from the interplay of both the restrictions imposed by cell membranes and their permeability, that is, $D_b \propto \langle x^2 \rangle t^{-1}$. If permeability is low, $\langle x^2 \rangle$ would be predominately determined by cell size. Generally, therefore, D_b is expected to be related directly to important cell characteristics. Here, we suggest a new option for diffusion mapping based on a combined analysis of the diffusion response with the models (a) – (c). A new map parameter is D_{comp} (Fig. 2b) which is obtained by setting $D_{comp} = D_b$ in any voxels where $K_{app} > 0.5$ (empirical value characterising essential deviations from the exponential function), and $D_{comp} = D$ otherwise. The areas of *quasi*-Gaussian and non-Gaussian diffusion can be discriminated in the maps of K_{app}, Fig. 2a. The histogram of D_{comp} in Fig. 2c demonstrates two clear peaks related to the two components of the distribution of the molecular mean square displacements in the investigated slice. The distribution component at smaller D_{comp} might be indicative for the distribution of the axon radii.

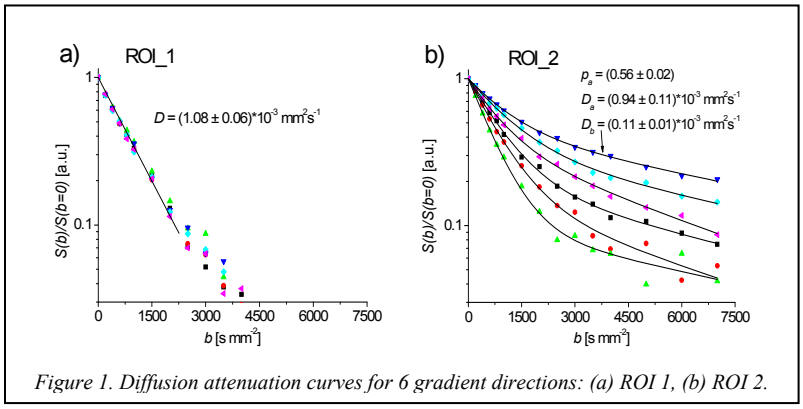

Figure 1. Diffusion attenuation curves for 6 gradient directions: (a) ROI 1, (b) ROI 2.

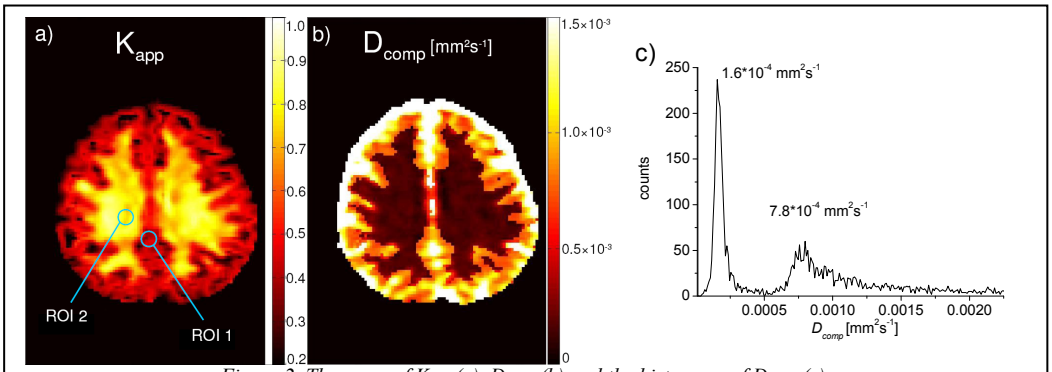

Figure 2. The maps of K_{app} (a), D_{comp} (b) and the histogram of D_{comp} (c).

Conclusions

New diffusion maps were constructed on the basis of measurements for large gradient strengths and duration. They are expected to have a potential use in monitoring maturation and ageing as well as in revealing pathological changes of brain white matter.

References

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