Interference of Inversion Recovery with Diffusion Weighted Imaging: Negative Apparent Diffusion Coefficients!

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Introduction

Diffusion weighted imaging (DWI) allows the determination of the apparent diffusion coefficient (ADC). Since several tissue compartments may be present in a voxel, e.g. tissue and cerebrospinal fluid [1] or tissue and blood [2], the measured ADC is an averaged value, weighted by these partial volumes. To reduce this partial volume effect, several investigators tried to null the magnetization of one or several compartments by using an inversion recovery (IR) technique [1,3,4]. Usually it is assumed that the two techniques, DWI and inversion recovery, may be applied without interference. The aim of this work was to evaluate whether this assumption is legitimate.

Material and methods

Image acquisition of the abdomen was performed on a 1.5T MR-scanner (Magnetom Avanto, Siemens Healthcare, Erlangen, Germany) using a twice refocused diffusion weighted EPI sequence in expiratory breathhold: b = 100 s/mm², TI = 50, 100,…1400 ms, global inversion, TR = 4400 ms, TE = 43 ms, matrix size: 100 x 78, FOV = 350 x 273 mm², 1 slice, slice thickness 5 mm, bandwidth 2940 Hz/px. The images were smoothed with a Wiener filter and subsequently registered using a non-rigid demon registration algorithm [5]. The measured signal of each voxel was fitted with a Levenberg-Marquardt algorithm.
Assuming a two compartment approach, the measured diffusion weighted signal S_{diff} was modelled, using:

$$S_{diff}(TI) = M_0 \cdot \left| f \cdot \left(1 - 2e^{-\frac{TI}{T1_B}} + e^{-\frac{TR}{T1_B}}\right) \cdot e^{-b \cdot D^*} + (1-f) \cdot \left(1 - 2e^{-\frac{TI}{T1_T}} + e^{-\frac{TR}{T1_T}}\right) \cdot e^{-b \cdot D} \right| \quad (1).$$

The signal decrease due to diffusion weighting is characterized by the strength of the diffusion weighting b and by the diffusion coefficients of the two compartments D and D*. The $T2$-weighted partial volume of the compartments is described by the parameter f. The factor M_0 is the equilibrium magnetization, which is determined by an initial measurement without inversion pulse. $T1_B$ and $T1_T$ are the longitudinal relaxation times of the two compartments.

Results

Figure 1 shows that the ADC measured in a single voxel inside the liver is clearly dependent on the inversion time. The solid line represents a fit of equation 1 and is in good agreement with the measured data points. Here, D*=0.02 s/mm² and $T1_B$ = 1441 ms [6] were fixed using empirical values to stabilize the fit. Without inversion pulse the ADC has a value of approximately 0.004 s/mm², whereas the graph shows a maximal value of 0.009 s/mm² at TI = 400 ms and a minimum of -0.007 s/mm² at TI = 500 ms. Thus, the ADC deviates by 0.016 s/mm² over a inversion time range of 100 ms. Figure 2 and 3 show two maps of the diffusion coefficient acquired at TI = 300 ms and TI = 750 ms, respectively. Counterintuitive negative diffusion is observed mainly in the liver and in regions with incomplete fat saturation and is most prominent at a TI of 750 ms.

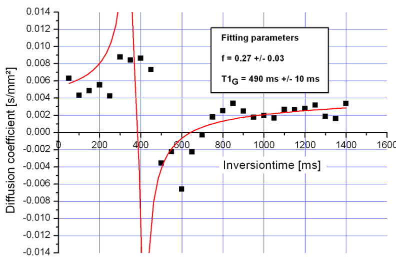

Fig.1: Graph of ADC vs. TI measured in one voxel inside the liver. The solid line represents a fit of equ.1 to the data points.

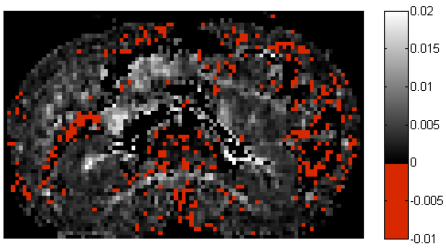

Fig.2: Map of the ADC inside the abdomen at TI = 300 ms; red areas mark negative ADC values.

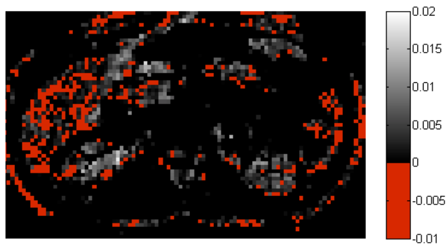

Fig.3: Map of the ADC inside the abdomen at TI = 750 ms, red areas mark a negative ADC values.

Discussion

The observed negative ADC can be explained using the two compartment model assuming different diffusion constants for each compartment. Under this assumption, consider the case where the 90° excitation pulse is applied at signal zero crossing. Here, one compartment may have a negative and the other a positive longitudinal magnetization. Due to the differing diffusion constants, the magnetization in the two compartments decay at different rates and the net magnetization deviates from zero, yielding a negative ADC. In conclusion this work proves the existence of an ADC(TI) dependence. Therefore, when diffusion weighted imaging is combined with inversion recovery, these effects should be taken in to account.

References

1 Hirsch et al (1999) MRI 17: 705-716
2 Le Bihan et al (1988) Radiology 168: 497-505
3 Herlihy et al (2001) AJNR 22:896-904
4 Young et al (2005) AJNR 26: 1551-62
5 Kroon et al: Institute for Biomedical Technology & Technical Medicine, Enschede, Netherlands
6 Stanisz et al (2005) MRM 54:507-12