Investigation of the theoretical background of the IVIM model using flow compensated DWI

A. Wetscherek[1], B. Stieltjes[2], W. Semmler[1], and F. B. Laun[1]
[1]Medical Physics in Radiology, German Cancer Research Center, Heidelberg, Germany, [2]Quantitative imaging based disease characterization, German Cancer Research Center, Heidelberg, Germany

Introduction

It was recently shown that abdominal diagnostics in pancreas [1] and liver [2] can benefit from using the intravoxel incoherent motion (IVIM) model introduced in 1986 [3]. The work at hand addresses a question that was already posed in 1988 [4], namely whether blood flow in capillaries changes its direction several times on the time scale of typical diffusion experiments as shown in Fig. 1, or whether it is merely the pseudo-random orientation of the capillaries that accounts for the bi-exponential signal decay observed in strongly perfused organs in diffusion weighted (DW) MRI. To tackle this question, flow compensated DW gradients are used for the first time in abdominal DWI.

Fig. 1: Does blood flow change direction during DW time?

Material and Methods

DW MRI data was acquired from 5 healthy volunteers (age 24-31) using a twice refocused single-shot EPI sequence with flow compensated imaging gradients at 1.5 T (Magnetom Avanto, Siemens Healthcare, Erlangen). During each expirational breath hold 6 DW directions at 2 b-values and a b_0 image were acquired (TR=1.5 s, TE=100 ms, BW=2500 Hz/px, matrix 88 x 66, resolution 3.5 mm, 7 slices, 5/1 mm thickness/distance). Bipolar and first moment nulled (flow comp.) DW gradient schemes of different total duration Δ were used with b-values ranged between 10-300 s/mm². For Δ = 50/60/70 ms TE was increased to 116.5/137/156 ms.

Results

Fig. 2 shows typical signal attenuation for ROIs in pancreas (a) and liver (b) normalized to mean magnitude of b_0 images. Data was averaged over directions and plotted logarithmically against b-value for both flow compensated and bipolar gradients. Error bars correspond to standard deviations of the different subjects. While the bipolar gradient data exhibits bi-exponential behaviour, signal attenuation from flow comp. gradients can be modeled by a mono-exponential decay. The apparent diffusion coefficient (ADC) determined by linear regression is plotted against Δ in Fig. 3. Due to the low number of volunteers, statistics of data are poor and definite conclusions on a particular trend cannot be drawn. Within errors estimated from regression, ADCs of flow comp. data appear independent of Δ/TE. The average ADC for Δ = 31-60 ms is 3.37±0.20 µm²/ms (pancreas) and 1.87±0.20 µm²/ms (liver).

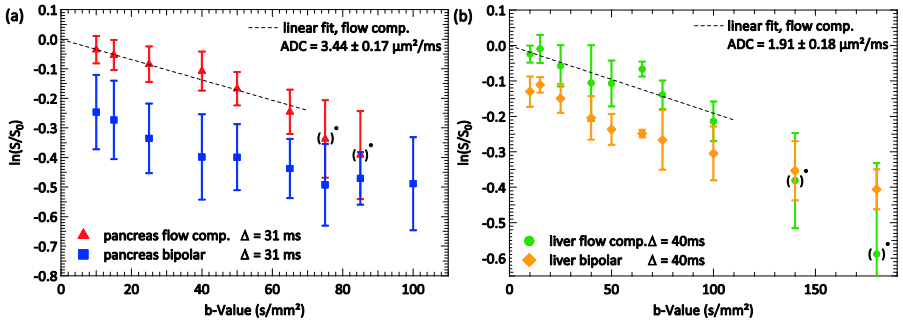

Fig. 2: Typical signal attenuation for ROIs in pancreas (a) and liver (b) normalized to mean magnitude of b_0 images. Errors bars show standard deviations of data from different subjects.

(*) Data was not used for regression as underlying images suffered from signal voids, probably due to eddy currents.
(**) Data for Δ = 70 ms has so far only been acquired once and suffered from very low SNR due to longer TE.

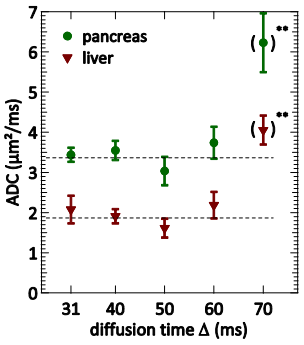

Fig. 3: ADC of flow comp. data from ROIs in pancreas and liver plotted against Δ.

Discussion

The presented data indicates that the bi-exponential signal decay in the strongly perfused organs such as pancreas and liver is reduced to a mono-exponential decay, if flow comp. DW gradients are employed. It was recently shown that using blood suppression in diffusion MRI of the pancreas eliminates the effects of perfusion on the signal, but the stated ADC value of 1.34±0.06 µm²/ms [5] differs clearly from the flow comp. ADC of 3.37±0.20 µm²/ms. Our ADC value seems reasonable, since liquids in the human body, like cerebrospinal liquid, show diffusion constants of 3 µm²/ms [6] and effects on signal attenuation due to non-laminar flow cannot be ruled out completely by the flow comp. diffusion weighting. Though it was shown for bipolar DW gradients, that signal decay for small b-values strongly depends on TE due to relaxation time effects [5], the attenuation by flow comp. DW appears to be virtually independent of Δ and TE. Our preliminary results would suggest that the typical timescale on which the blood changes its direction during the microcirculation in capillaries is at least of the order of the typical time of a diffusion weighting experiment. Despite the increased susceptibility to eddy currents, the use of flow compensated DW gradients in abdominal DWI may prove useful to reveal changes in vascularization structure: dominating net flow effects are suppressed, while signal attenuation is still sensitive to blood and thus capillary dimensions.

References

[1] A. Lemke *et al.*, Invest Radiol **44**, 12 (2009); [2] A. Luciani *et al.*, Radiology **249**, 3 (2008); [3] D. Le Bihan *et al.*, Radiology **161**, 2 (1986);
[4] D. Le Bihan *et al.*, Radiology **168**, 2 (1988); [5] A. Lemke *et al.,* Magnet Reson Med (2010); [6] S. Mori, *Diffusion Tensor Imaging*, Elsevier (2007)