Evidence for a vascular contribution to the biexponential signal decay as a function of the b-value in DWI: A verification of the IVIM-model

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Introduction:

Since the IVIM-Theory was developed by Le Bihan in 1988 [1], diffusion weighted imaging (DWI) has been regarded as a potential tool to quantify microperfusion in addition to diffusion. The separation of real diffusion and microperfusion has been discussed [1, 2], but has not been proved yet by a well-controlled experiment in humans. Moreover microperfusion is still not completely accepted as the reason for the biexponential signal decay as a function of *b* at low *b*-values that has been observed especially in the abdomen [3, 4]. Therefore the aim of this study was to investigate the vascular contribution to the DWI-measurement in abdominal tissue with a vascular suppression technique.

Materials and Methods:

DWI-images of five healthy volunteers were acquired with and without suppression of the blood signal at 1.5 Tesla (Magnetom Avanto, Siemens Medical Solutions, Erlangen). A global Inversion Recovery (IR) technique (TR/TI = 2800/800 ms) was used. The first excitation pulse is applied globally so that the magnetization reaches steady state. All further excitations are applied slice-selectively and the signal of the first excitation pulse is discarded. The 180° pulses in the twice-refocused spin echo (TRSE) diffusion preparation were neglected in the calculation of the optimal TI. Axial DWI was performed using a single-shot echo-planar imaging (SE-EPI) pulse sequence in expirational breath-hold: TE = 50 ms, matrix size = 100x78 with a 3.5 mm pixel resolution, one slice, slice thickness = 5 mm, 2 averages, bandwidth = 3000 Hz/pixel and a total measurement time of 9 minutes. The acquisition was separated into 7 blocks (b_0, b_{25}), (b_0, b_{50})…(b_0, b_{300}) and each block was acquired in a single breath-hold (TA = 30 ms) to avoid motion artefacts. Diffusion weighted images were acquired with three orthogonal gradient directions. DWIs without suppression of the blood signal were acquired directly afterwards using the same parameters, but without inversion pulses. Regions of interest (ROI) were placed in the pancreas parenchyma and in the liver tissue to calculate the signal intensity for all *b*-values. Using the biexponential IVIM-approach [1], the perfusion fraction *f* and the diffusion coefficient *D* were extracted for every volunteer, while the pseudo diffusion coefficient *D** was remained constant (D* = 0.02 mm²/s) to stabilize the fit. A pair wise Mann-Whitney U-test was used to test for statistically significant differences between the data with and without suppression of the blood signal.

Results:

Figure 1 demonstrates the successful suppression of the blood signal in the DW-sequence. On both images the vascular components (indicated by red arrows) are dark, whereas the liver and the pancreas (white arrow) still provide enough signal (SNR>15 in the diffusion weighted image). With suppression of the blood, the signal decay as a function of *b* is monoexponential in pancreatic tissue and the extracted perfusion fraction f decreases in comparison to the biexponential signal decay without suppression, as seen exemplarily in figure 2. Similar results were found in the liver tissue, where the ROIs were in the liver parenchyma. Table 1 shows the mean values of *f* and *D* that were individually calculated for each volunteer. The suppression of the blood signal causes a significant reduction of the perfusion fraction *f*, whereas the diffusion coefficient *D* does not change significantly. The higher relative standard deviation of the parameters that were extracted from the data with blood suppression arises from overfitting the monoexponential signal decay to a biexponential function.

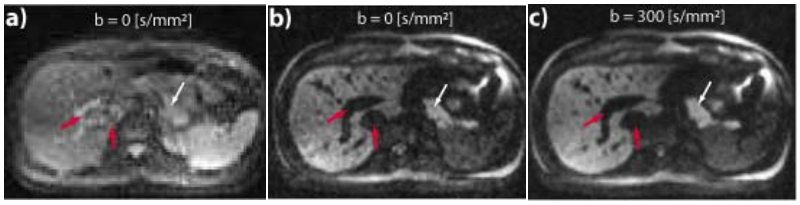

Fig. 1: The unweighted image without suppression a) and one block of DWIs with suppressed blood signal (b, c). The arteries indicated by red arrows are suppressed, whereas the pancreas (white arrow) and the liver show sufficient signal (SNR>15).

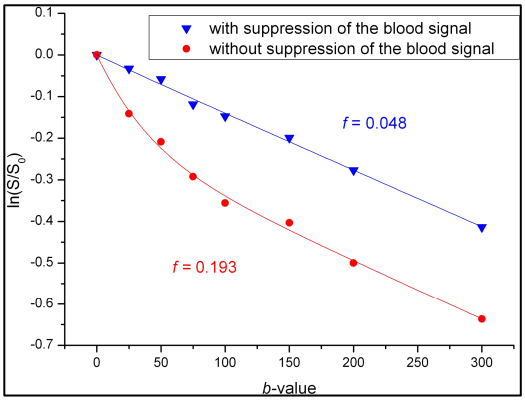

Fig. 2: Biexponential fit of the DW signal decay as a function of *b* in the pancreas of a volunteer with and without suppression. The biexponential behavior and therefore the perfusion fraction *f* are minimized after suppression of the blood.

Discussion:

This study verifies that a vascular component induces a faster signal decay at low *b*-values in liver and pancreatic tissue. This causes a dependence of the measured ADC on the applied *b*-value showing the validity of the IVIM-model that allows for the separation of diffusion and perfusion effects in DWI.
Thus, the derived parameter *f*, gives additional information on tissue perfusion that may aid the differentiation of healthy and diseased organs.

	pancreas		liver	
	f	*D* in 10^{-3} mm²/s	*f*	*D* in 10^{-3} mm²/s
with suppression	0.046±0.038	1.21±0.77	0.027±0.031	1.16±0.93
without suppression	0.272±0.061	1.12±0.27	0.184±0.045	1.02±0.26
p-value	0.008	0.51	0.008	0.69

Tab. 1: Extracted parameters of all volunteers with and without suppression of the blood signal. The perfusion fraction *f* in the liver and the pancreatic tissue is significantly lower after blood suppression.

References:

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