Investigation of prostate cancer using diffusion weighted IVIM imaging

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Introduction:
Diffusion-weighted Imaging (DWI) and the derived apparent diffusion coefficient (ADC) were reported by several groups [1,2] to differentiate cancerous and healthy tissue in the prostate. The Intravoxel Incoherent Motion (IVIM) Theory, which predicts an additional component in the signal equation due to perfusion [3], could recently be applied to the liver and the pancreas [4,5]. Furthermore, it was possible to identify lesions by means of the extracted parameters. In this work, the decrease of the ADC in prostate cancer compared to healthy tissue is investigated using the IVIM-Theory. Moreover, the extracted parameters and the calculated parameter maps are analyzed with regard to the differentiation between cancerous and healthy tissue.

Methods:
Diffusion-weighted images of the prostate were acquired from 9 patients with histologically proven prostate carcinoma (prostatectomy) using an optimized single-shot echo planar imaging (EPI) sequence at 3 Tesla (Magnetom Tim Trio, Siemens Medical Solutions, Erlangen, Germany) with an endorectal coil: TR/TE = 3300/88 ms, 20 slices with 3 mm thickness, matrix = 136x136, bandwidth = 1600 Hz/Px and an isotropic inplane resolution of 1.5 mm. The diffusion weighting was performed applying four b-values (b = 0, 50, 500, 800 s/mm²). Anatomical scans included an axial T_2-weighted turbo spin-echo sequence (TR/TE = 3580/101 ms, slice thickness = 3.8 mm).
The following parameters were extracted from the diffusion weighted images: The ADC via a mono-exponential fit and the diffusion coefficient D, the pseudo diffusion coefficient D^*, and the perfusion fraction f via a bi-exponential fit according to [3]. On the parameter maps, calculated with a home-written Matlab program (The MathWorks, Natick, Massachusetts), regions of interest (ROIs) were placed in cancerous and healthy tissue using the information of histological findings. A non-parametric Wilcoxon test was used to analyze whether differences existed between the tumor and the healthy prostate tissue.

Results:
Fig.1 shows a T2-weighted anatomical slice of a patient with prostate cancer, Fig. 2 the calculated ADC map of the same slice. The ADC of the tumor (red ROI) is considerably decreased compared to the surrounding tissue (green ROI).
Fig. 4 shows the signal decay against the b-value in the two ROIs of Fig. 2. Both the perfusion fraction f and the pseudo diffusion coefficient D^* are lower in cancerous than in healthy tissue. Hence, in the f map (Fig. 3) the carcinoma appears darker than the surrounding tissue (red arrow).
Tab.1 shows that the ADC and f are significantly decreased in cancerous tissue compared to healthy tissue for all examined patients ($P \leq 0.0039$), whereas D and D^* were not significantly different in both tissues.

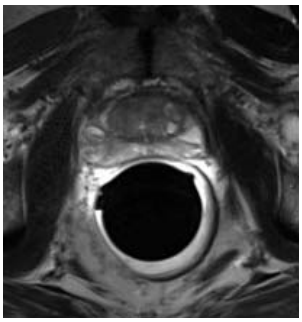

Fig. 1: T2-weighted anatomical image of the prostate

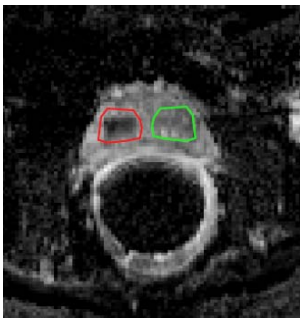

Fig .2: ADC map with ROIs in cancerous (red) and healthy tissue (green). The tumor corresponds to the hypointense area

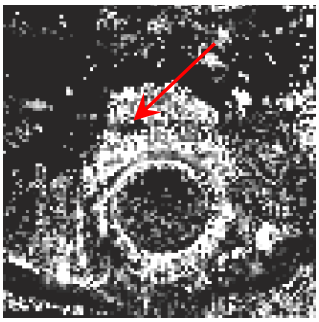

Fig .3: f map of the same slice. The perfusion fraction is decreased in the cancerous tissue (arrow)

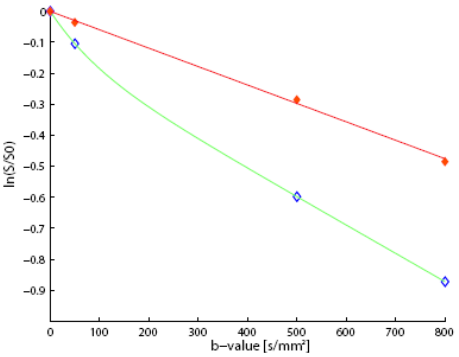

Fig .4: IVIM-fit of the ROIs from Fig. 2 in healthy (green) and cancerous tissue (red)

Discussion:
The presented preliminary results confirm that the ADC obtained by mono-exponential fitting is notably increased by perfusion effects [6]. In the presented study, the perfusion fraction is decreased in cancer compared to healthy tissue. This suggests that reduction of the ADC in cancer primarily comes from a decreased perfusion fraction and not from restricted diffusion.
As far as we now, the hereby presented f map is the first IVIM parameter map of the prostate. However, the large variances of the perfusion fraction limit the image quality compared to the ADC map. This might be improved by the use of more b-values at the expense of longer scan times. The higher vascularity of cancerous tissue measured with DCE-MRI by Ito et al. [7] seems contradictory to our results. Therefore, simultaneous measurements of DCE and IVIM parameters should be performed in future studies.

	ROI in cancer	ROI in healthy tissue	P
ADC [µm²/ms]	0.75 ± 0.13 [0.55 - 0,90]	1.57 ± 0.26 [1.10 – 2.01]	0.0039
D [µm²/ms]	0.69 ± 0.10 [0.49 – 0.82]	1.08 ± 0.47 [0.04 - 1.55]	0.0977
D^* [µm²/ms]	5.33 ± 4.36 [0.00 – 9.10]	6.11 ± 4.21 [1.76 - 13.95]	0.6523
f [%]	7.17 ±5.70 [0.00 – 15.78]	36.34 ± 22.91 [13.00- 84.53]	0.0039

Tab.1: Mean, standard deviation, and range of the fitting parameters for the 9 patients

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