Comparison of Different Models for Analysis of Renal Diffusion Imaging

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Introduction: Compared to the standard mono-exponential approach to analyze diffusion weighted MRI data, the application of more complex models can result in valuable additional insight into pathological processes. This work compares results from mono-exponential, stretched-exponential, diffusional kurtosis and bi-exponential models, which were applied to analyze renal diffusion imaging data sets. In a first step, reference data for each model was obtained from 5 healthy subjects. The reference model parameters were then compared to results from renal pathologies.

Methods: Studies were performed on a 1.5T whole body system (Magnetom Avanto, Siemens, Germany). The kidneys of 5 healthy subjects and 2 patients with focal kidney lesions (Patient 1: benign cortical cyst; Patient 2: Multifocal papillary renal cell carcinoma (RCC)) were investigated during free breathing with a single-shot EPI DWI sequence with 8 b-values of 0, 10, 40, 70, 120, 250, 450, and 700s/mm^2. Other imaging parameters were: matrix:156x192, voxel size:2.4x2.2x6.0 mm^3,TR=3700ms, TE=65ms, 4 averages. Acquisition time was 5 min 38 s using parallel imaging with an acceleration factor of 2 and partial Fourier acquisition. Four different models were fitted to the data on a pixel by pixel basis using MatLab (Mathworks, Natick, Mass). Eq.1 describes the mono-exponential diffusion model (1) with the apparent diffusion coefficient as parameter of interest. The stretched exponential model (2) including the stretching parameter α, that defines the deviation of the signal decay from a mono-exponential and the distributed diffusion coefficient DDC is given by eq.2.The Kurtosis model (3) described by eq.3 results in an apparent diffusion coefficient D_{app} and the diffusional kurtosis K_{app}. The bi-exponential model (4) as given by eq.4 consists of the perfusion fraction f, the diffusion coefficient D_1 and the pseudo-diffusion coefficient D2. S(b) is the signal measured at a given b-value, S_0 is the signal amplitude in the absence of diffusion weighting.

$$S(b)/S_0 = \exp(-b \times ADC) \quad [1]$$

$$S(b)/S_0 = \exp(-(b \times DDC)^{\alpha}) \quad [2]$$

$$S(b)/S_0 = \exp(-bD_{app} + \frac{1}{6} b^2 D_{app}^2 K_{app}) \quad [3]$$

$$S(b)/S_0 = (1-f)\exp(-bD_1) + f\exp(-(bD_2)) \quad [4]$$

Results and Discussion: Fig 1-3 show the pixel wise fit results from the kidneys of one healthy volunteer and the two patients. Fig 4 presents the average values of the fit results of the five healthy subjects, as well as ROI-based values from the focal pathologies present in patient 1 and 2. Both the stretched exponential model and the kurtosis model provided solid fit results for the parameters α and K_{app}, respectively. While the cyst is characterized by an α-value close to 1, the two RCC lesions show a clear deviation from mono-exponential behavior with α-values around 0.5. This deviation from Gaussian diffusion is even more pronounced in the kurtosis maps, where both RCC-lesions can be clearly differentiated from healthy parenchyma by their higher K_{app}, which is consistent with reduced diffusivity in the tumor due to high cellular density. Compared to the other approaches the application of a bi-exponential model to our data resulted in a very high variability of the resulting parameters and in addition did not allow for a clear discrimination of tissues.

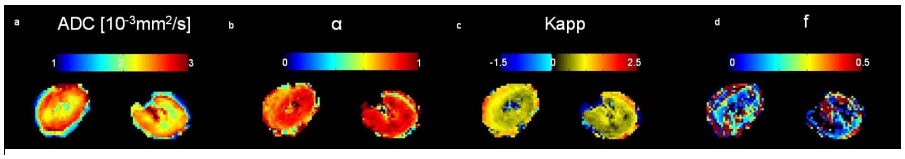

Fig. 1: Fit results from one healthy volunteer.

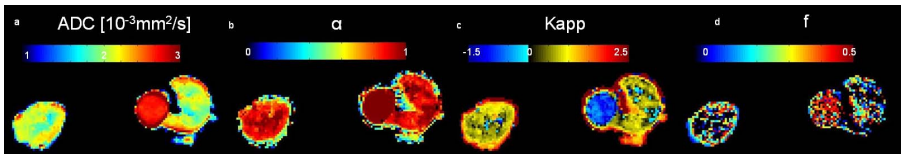

Fig. 2: Fit results from one patient with a cyst.

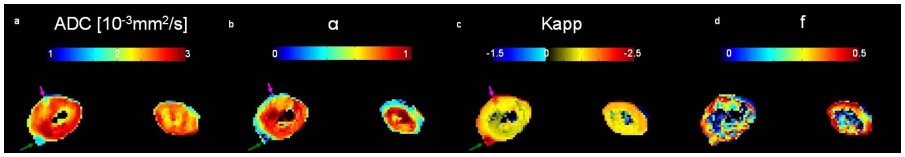

Fig. 3: Fit results from one patient with two tumors (pink and green arrows).

Conclusion: Quantification of renal DWI data by stretched exponential and diffusion kurtosis models result in additional parameters that may facilitate the better characterization of different tissue types like RCCs.

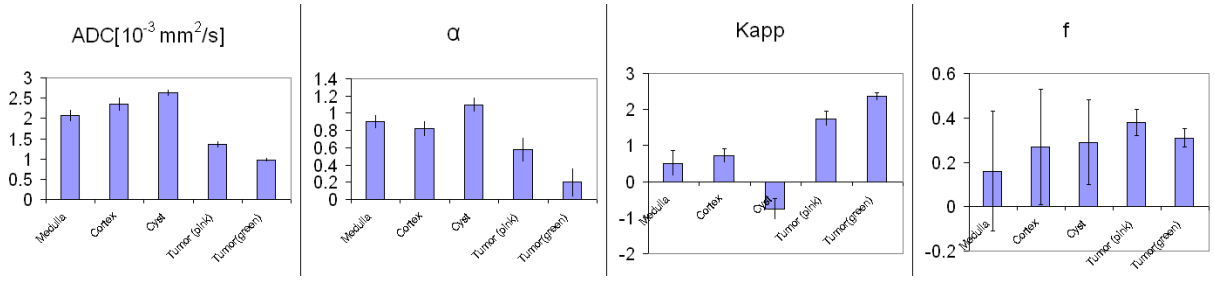

Fig. 4: Fit results of the average values of five healthy volunteers, one cyst, and two RCC lesions

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References: (1) Le Bihan et al. , *Radiology* 161(1986), (2) Bennett et al. , *MRM* 50(2003), (3) Jensen JH et al. , *MRM* 53(2005), (4) Le Bihan et al. , *Radiology* 168(1988),