DTI in human kidney: Image co-registration improves signal stability and lowers variability in diffusion parameter estimation

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Introduction: Recently, several diffusion tensor imaging (DTI) studies have been performed in the kidney [1-6]. The fractional anisotropy (FA) provides additional structural information to ADC, like tubule arrangement and integrity. One major problem in abdominal DTI is related to physiological motion artifacts caused by respiration leading to image artifacts, blurring and signal voids. Abdominal DTI scans are therefore performed either during a breath-hold period or employing respiratory triggering. However, even in triggered scans, residual motion remains, thus possibly increasing variability of determined diffusion parameters due to the inclusion of different tissue types in the ROI.
In addition to diffusion, microperfusion may contribute in DWI measurements of the abdomen [7]. Previously we have separated diffusion and microperfusion contributions in renal DWI scans [8]. However, the estimation of the perfusion contribution (F_P) demonstrated a relatively large variability, which may in part be due to residual motion.
The aim of this study was therefore to employ prior to further analysis non-rigid image registration of individual echo planar (EP-) DTI images of human kidneys, which are acquired within fractions of a second and are therefore virtually free of motion artifacts, and to compare the variability of the determined diffusion parameters and image blurring with the standard processing. Co-registration of individual images has been performed previously frequently for different MRI modalities and for different organs; however, we are not aware of a study assessing the value of image co-registration in DTI measurements of abdominal organs.

Methods: Twelve healthy volunteers (8 female, 4 male, age=27.5y±7.0y) were examined on a 3T MR scanner (Siemens TIM Trio, Erlangen Germany). A DW single shot echo-planar imaging sequence was applied with ten different b-values between 0 and 700s/mm^2 in 6 non-collinear directions. Further parameters were: 7 coronal slices, FOV=30×30cm^2, slice thickness=5mm, gap=2mm, acq.=2, parallel imaging (GRAPPA factor=3), BW =2300Hz/px, matrix=128×128, respiratory triggering, TR_{min}=3300ms, TE=66ms, with a minimal acquisition time of TA_{min}≈6min.

Co-registration of the individual images was performed using an in-house developed multimodal non-rigid registration software, based on point-wise mutual information [9]. Further data processing for both, the original and the co-registered images included biexponential fitting, yielding ADC and the perfusion fraction F_P, and calculation of FA. Six regions of interest (ROI) were placed on several slices for each subject in medulla and in cortex, and merged separately. Identical ROI positions were used for co-registered and original images. The co-registered and original images were compared in two ways:
1) For each ROI the standard deviation (SD) was calculated for the diffusion parameters obtained from all pixels within the ROIs and compared,
2) The deviation from diffusion-model fitting was determined comparing the root mean squared error (RMSE). RMSE was determined for fitting the signal only for b-values b<100 sec/mm^2 ($RMSE_{low}$), for b-values b>100sec/mm^2 ($RMSE_{high}$), and for fitting all b-values ($RMSE_{tot}$).

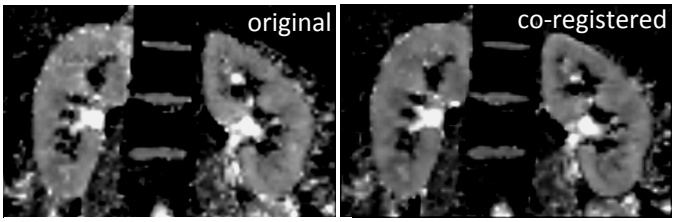

Fig. 1: Comparison of ADC maps

		ADC [10^{-5}mm^2/sec]		F_P [%]		FA	
		mean	SD	mean	SD	mean	SD
medulla	original	194	16	0.15	0.06	0.38	0.09
	co-reg	198	12	0.13	0.05	0.35	0.07
	p-value	>0.1	<0.001	<0.001	<0.001	<0.001	<0.001
cortex	original	203	12	0.17	0.05	0.23	0.06
	co-reg	208	9	0.14	0.04	0.20	0.05
	p-value	<0.01	<0.001	<0.002	<0.002	<0.001	<0.001

Table 1: Comparison of ADC, F_P and FA in kidneys derived from original and co-registered images. SD denotes the mean standard deviation of parameters in ROIs, not between subjects.

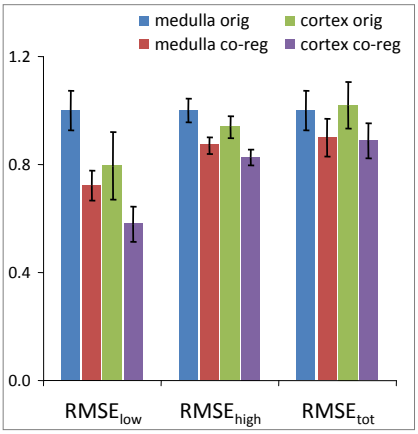

Fig. 2: Comparison of RMSEs in medulla and cortex between signals from original and co-registered images as a measure for signal variability

Results: Visual inspection of the diffusion parameter maps demonstrated less distortions in co-registered images (Fig. 1).
Quantitative analysis demonstrated clearly reduced signal variations in co-registered scans: 1) The SDs of all parameters within the ROIs were significantly lower in co-registered images (Table 1). The mean values of F_P, ADC and FA were also slightly but significantly different; 2) All RMSEs were significantly lower in co-registered images demonstrating improved signal stability (Fig.2). The greatest reduction in RMSE was obtained for $RMSE_{low}$, i.e. for fitting the signals for low b-values.

Discussion & Conclusions: The significantly lower SDs and RMSEs clearly demonstrate the benefit of performing co-registration of individual EP-images in DTI measurements of the kidney. It is important to note, that this improvement comes at no costs, e.g. the acquisition time is not prolonged. The parameters ADC, F_P and FA are most likely different between the co-registered and original images also because of better signal stability, due to lower spurious inclusion of signals from other tissue, e.g. from pelvis with different diffusion characteristics. The co-registration method may benefit in addition also diffusion measurements in other organs or in transplanted kidneys, which may be measured without triggering, since motion artifacts due to respiration are less severe.

References:

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