Segmentation of renal structures in distortion corrected diffusion-weighted echo-planar images based on anatomical FSE and GRE images

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Purpose

Diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI) has successfully applied in the past for tissue characterization and lesion detection[1]. Especially, DTI has been shown to be a useful tool for analyses of renal composition and function[2]. However, the internal structures like medulla and cortex are not always easily to differentiate in both, diffusion-weighted images and calculated parameter maps. The segmentation of the kidney and their cortical and medullar components in highly resolved fast-spin-echo (FSE) or gradient-echo (GRE) anatomical images[3] has been successfully demonstrated. A simple transfer of the segmented areas to DTI images is, however, problematic because of geometric distortions due to susceptibility problems resulting in static field inhomogeneity. Distortion correction methods have been suggested to remove these artifacts mostly applied in brain studies[4, 5]. The purpose of this study was to assess the feasibility of segmentation of the entire kidneys and their internal renal structures in distortion corrected DTI images based on high resolution anatomical imaging.

Methods

Six healthy volunteers were examined on a clinical 3T MR scanner (Skyra, Siemens Healthcare, Erlangen, Germany) with anterior and posterior array coils. T2-weighted (w) FSE and T1-w GRE sequences were applied for anatomical segmentation, and diffusion-weighted single-shot spin-echo echo-planar (DW-SE-EPI) sequences were acquired for coronal slice orientation (sequence parameters see Table 1). DTI data were collected with two different phase-encoding directions (Head-Feet, H>>F, and Feet-Head, F>>H), resulting in pairs of images with distortions going in opposite directions. From these image pairs the susceptibility-induced off-resonance field was estimated using the FSL tool[6], where two images were combined into a single corrected one. The reference masks for each volunteer were carefully drawn manually in each image slice using Matlab (Math Works, Natick, USA). These masks were then superimposed to the calculated mean diffusivity (MD) and fractional anisotropy (FA) maps and qualitative analysis was performed by visual inspection. To show the homogeneity of the renal structure, the standard deviation (sd) values of the masks in the distortion corrected and uncorrected maps were then compared using Wilcoxon test. P values < 0.05 were considered statistically significant.

	T2-w FSE	**T1-w GRE**	**DTI**
TE (ms)	92	3.21	85
Acq. matrix	320 × 320	224 × 320	129 × 192
FOV (mm^2)	400 × 400	400 × 400	400 × 400
Phase resolution (%)	100	70	67
Phase FOV (%)	100	100	100
Partial Fourier	4/8	7/8	6/8
Parallel acq. factor	2	2	2
BW (Hz/Pixel)	710	260	1736
Averages	1	1	1
b-values (s/mm^2)	-	-	0, 400
Diffusion-directions	-	-	30
Number of slices	16	16	16
Slice thickness (mm)	3.5	3.5	3.5
TR (ms)	2000	120	1700
	breath-hold	breath-hold	respiratory-triggered

Table 1: *Sequence parameters for T2-weighted FSE, T1-weighted GRE and DTI imaging.*

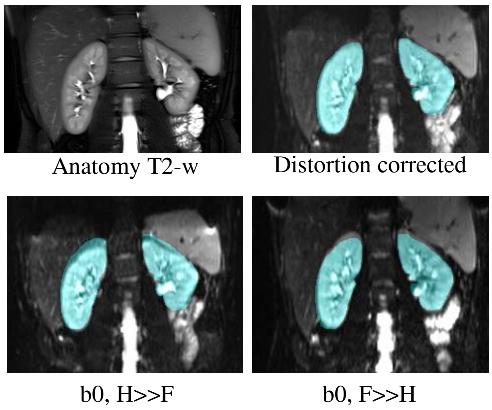

Figure 1: *Qualitative comparison of the manual segmentation superimposed to b0 images of DTI data collected with reversal phase-encoding direction (H>>F and F>>H) and resulted distortion corrected image.*

Results

The qualitative comparison of the anatomical and distortion corrected echo-planar images of the kidneys showed clearly better agreement compared to uncorrected images. Figure 1 shows the manual segmentation of entire kidneys superimposed to DTI images with opposite phase-encoding direction and to a distortion corrected image. FA/MD sd values in the cortex and medulla from distortion corrected images were significant smaller (FA_C: $p<0.0001$, MD_C: $p=0.0009$ and FA_M: $p=0.0464$) than in uncorrected (H>>F) images (Figure 2). Furthermore, the mean FA values for cortex (0.32) and medulla (0.33) from uncorrected maps are nearly identical, whereas mean FA values of corrected maps show clearly visible difference between cortex (0.22) and medulla (0.27).

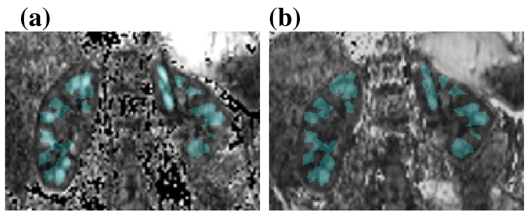

Figure 2: *Qualitative comparison of distortion corrected (left) and uncorrected (right) FA maps with super-imposed medulla mask.*

Discussion

It has been demonstrated that DTI values in specific renal areas can be accurately determined by the manual segmentation of the kidneys in highly resolved anatomical images. In this preliminary study a co-registration of DTI data, acquired with respiratory triggering, was not yet performed. Although by registering the DW-EPI images on the first b0-image the possible shifts can be minimized, the DTI gradient directions must be also corrected corresponding to the rotation and displacement parameters of the registration. This is still a problem but will be attached in future studies.

References

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