Medullar architecture mapping of the human kidney in vivo using an optimized DTI protocol at 3 T

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Purpose

The kidneys are extracranial organs promising for Diffusion Tensor Imaging (DTI) applications due to their anisotropic tissue architecture [1]. Previous studies in healthy volunteers have demonstrated that the diffusion anisotropy is significantly higher in the medulla than in the cortex [2-6]. It was reported that DTI measurements of the kidneys at 1.5 T [2] and 3 T [3] allow for discrimination between cortex and medulla in healthy volunteers using single breath-hold parallel imaging. Recently DTI studies of the kidney with respiratory triggering were reported [4-6]. However, the precision of the diffusion measurements of those studies is limited by single breath-hold [1-3], low spatial resolution, small number of directions for the diffusion weighting, or small number of slices [1-6]. The aim of the present study was to develop an optimized DTI protocol for the assessment of the renal medullar architecture.

Materials and Methods

Experimental setup: Four volunteers were examined in a 3 T MRI system (Siemens Healthcare, Erlangen, Germany). The body coil was used for RF transmission and a 6×6-channel anterior-posterior phased array coil was applied for signal detection. For respiratory triggering, a respiratory belt was used. An adapted triggering scheme was implemented allowing for the acquisition of all images in expiration. In this scheme only a subset of slices is acquired after the trigger pulse. The sequence then waits for another trigger pulse before collecting the next group of slices.

Diffusion Imaging: For determination of the diffusion tensor a diffusion-weighted echo-planar imaging (EPI) sequence was applied using a monopolar diffusion preparation according to the Stejskal-Tanner scheme [7]. The kidneys were imaged in coronal orientation slightly tilted along the long axis of the organ. Ten slices were acquired in two groups with a slice thickness of 3 mm covering both kidneys. Each slice group was acquired within TR=560 ms. The image matrix was 192×192 and the field of view (FOV) 384×384 mm^2, leading to a voxel size of 2×2×3 mm^3. The chosen b-value was 400 s/mm^2 and the diffusion-sensitizing gradients were applied along 30 different directions. Additionally a non-diffusion weighted image was acquired (b0-image). Receiver bandwidth of 1638 Hz/Px, parallel imaging factor of 2 and partial Fourier mode of 6/8 were applied leading to TE=66 ms. Whole imaging time varied between 4-6 min, depending on the individual respiration rate of the participant.

DTI Data Analysis: The acquired diffusion measurements along 30 directions were fitted to the 3×3 symmetric matrix of the diffusion tensor using a 3D ellipsoid model. Frequently used rotationally invariant parameters are the fractional anisotropy (FA) and mean diffusivity (MD). FA, MD and color-coded principal eigenvector maps were generated using the DTI task card software from the manufacturer. For quantification of FA and MD, cortical and medullar regions of interest (ROIs) were manually positioned in the b0-images for all slices. For tractography, the diffusion data were pre-processed on a stand-alone PC using the Medinria software [8].

Results

The proposed diffusion-weighted sequence provided images with good quality in all subjects without substantial spatial distortions induced by eddy currents. Fig. 1 shows an example of the DTI data of the kidneys for one slice. The MD map shows only a low contrast, whereas the FA map indicates striking contrast between the medulla and the cortex. ROI analysis for medulla and for cortex revealed substantially higher FA in medullar (0.54±0.02) than in cortical (0.22 ± 0.01) areas, while only slight differences were observed regarding MD (2.0 ± 0.04 vs. 2.3 ± 0.04). A fusion of color-coded principal eigenvector diagrams with related anatomical slices (b0-images) is shown in Fig. 2 (left). The diagrams depict the local direction of maximal diffusion consistent with the radial orientation of the medullary tubules. In Fig. 2 (right), tractography of the same kidney is presented, demonstrating medullary diffusion anisotropy. In the medullary pyramides, DTI rays are orientated in a radial architecture, originating at the corticomedullary border and terminating in the papilla. In contrast, no specific ray architecture could be identified in the cortex.

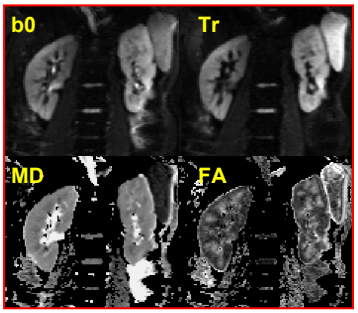

Figure 1: *DTI data obtained from a healthy volunteer. EPI non-diffusion weighted image (**b0**), trace-weighted image (**Tr**), mean diffusivity (**MD**) and fractional anisotropy (**FA**) maps are shown for one paracoronal slice.*

Discussion

Measurement of anisotropy of the renal medulla is challenging due to respiratory movement, lack of SNR and limited spatial resolution. In the present work, an imaging protocol addressing all these problems was developed and applied. The most important feature of this protocol is the use of respiratory triggering, which allows for the acquisition of high resolution diffusion weighted images of the entire kidney with a slice thickness of 3 mm. Furthermore, it permits acquisition of 30 diffusion gradient directions, allowing more accurate tractography. Additionally, the monopolar diffusion preparation scheme enables using short TE, thus providing higher SNR. The protocol allows for tractography of renal medullar tissue with excellent image quality. The specific diagnostic advantage for the analysis of renal pathologies with better differentiation of anatomical and functional renal structures needs to be evaluated in future clinical studies.

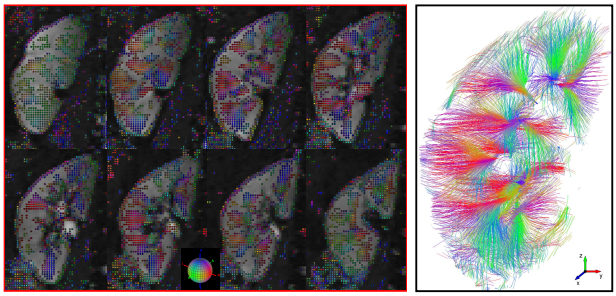

Figure 2: *(**left**) Color-coded principal eigenvectors diagrams showing the local direction of maximal diffusion in eight central slices calculated from the acquired DTI data. The diagrams are fused with corresponding anatomical images (b0-images). For calculation, a FA threshold of 0.25 and a background removal threshold of 100 were used. (**right**) Tractography of the same kidney as shown in Figure 1 provides a spatial impression of the radial organized diffusion pattern of the renal medulla. The DTI rays were calculated using following parameters: FA-threshold 0.25; background removal threshold, 200.*

References

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