Diffusion Tensor Imaging of In Vivo Human Kidney at 3 T : Robust anisotropy measurement in the medulla

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Background

Function and structure of the renal tubules is of great importance in better understanding pathophysiology of renal failure [1, 2]. Diffusion tensor imaging (DTI) has potential for non-invasively exploring the functional and structural status of the kidney. There is limited data describing diffusion anisotropy of the kidney at 1.5T [3-5]. These studies have demonstrated higher diffusion anisotropy in the medulla with respect to the cortex. Our goal for the current study was to examine FA and other indices of diffusion anisotropy of the kidney at 3T in normal volunteers.

Methods

Scans were performed on 3 healthy volunteers (ages 32-35, male and female, in normal hydration status) at 3 T (Trio, Siemens Medical Solutions). Magnetization-prepared gradient echo images (MPRAGE) were acquired for anatomical reference. DTI data was acquired with a double echo, bipolar diffusion gradient, EPI sequence (EPI-DTI) using 2.1 x 2.1 x 6 mm voxel, coronal slices, 132x192x3 matrix, parallel imaging (GRAPPA) factor 2 w/ 24 reference lines, 5/8 partial Fourier, TR/TE = 1000 / 68 ms. Within one breathhold, an unweighted (b0) image and diffusion-weighted images at b=500 s/mm^2 for 6 diffusion gradient directions were acquired for 3 slices and 3 averages. 3 breathhold scans were acquired for a total of 9 averages. 5 out of 189 images were excluded due to very poor quality. All images were registered to the b0 image before averaging, and a 2x2 median filter was applied to the averaged images. Mean diffusivity (MD), fractional anisotropy (FA), and principal eigenvector maps were generated using homegrown code in Igor Pro (Wavemetrics, Inc.).

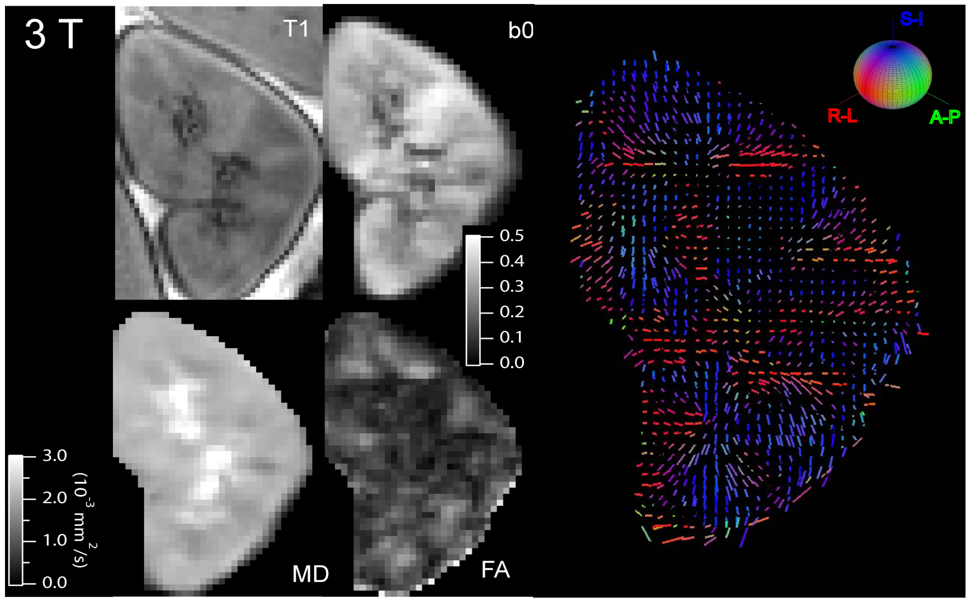

Figure 1: Diffusion tensor imaging (DTI) results for in vivo healthy volunteer kidney at 3 T. T1-weighted gradient echo image (T1), EPI non-diffusion weighted image (b0), mean diffusivity (MD), and fractional anisotropy (FA) maps are shown for one coronal slice. Right : color-coded principal eigenvector diagram showing the local direction of maximal diffusion. Vector lengths are scaled by the FA. The radial orientation of medullary tubules relative to the urinary tract is evident.

Results

Figure 1 shows results for one coronal slice through the middle of the kidney in one volunteer. The images show normal corticomedullary differentiation. T1-weighted image and b0 images show comparable contrast. The MD map shows slight contrast, but less dramatically than the relaxation weighting. In contrast, the FA map shows striking contrast between the anisotropic medullary tissue and the more isotropic cortex. The principal eigenvector map is consistent with the expected radial orientation of the medullary tubules in relation to the central urinary tract. This structure is discernible in several medulla chambers around the periphery of the kidney. Figure 2 shows MD and FA indices in several ROIs, including medullary, cortical, and urinary tract regions. The average medulla FA = 0.21 ± 0.02 is significantly greater ($p=0.004$) than in cortex (FA = 0.10 ± 0.03), while the MD values are comparable ($MD_{medulla}$ = 2.08 ± 0.10 μm^2/ms vs. MD_{cortex} = 2.15 ± 0.11 μm^2/ms).

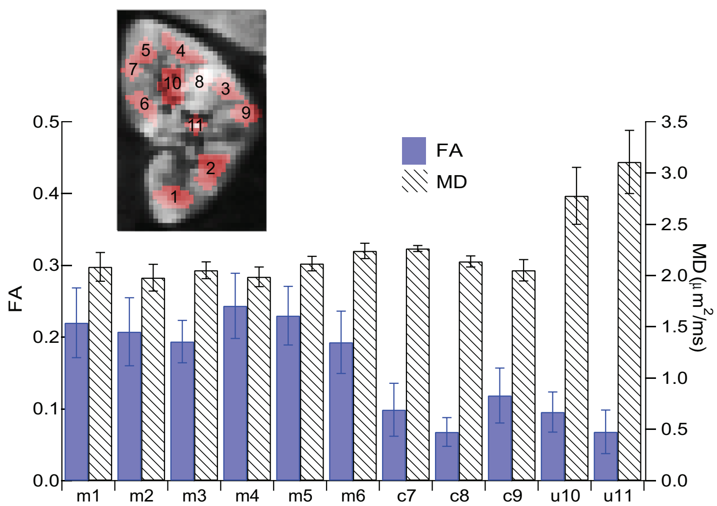

Figure 2: ROI mean diffusivity (MD) and fractional anisotropy (FA) values from in vivo kidney DTI at 3 T. Results in medulla (M), cortex (C), and urinary tract (U) are shown. On average, FA provides higher medullary-cortical contrast than MD.

Discussion

DTI of the kidney is challenging for a number of reasons, including the need for breathhold acquisitions, image registration, and low FA values (0.2-0.4) even in the most anisotropic medullary component. In such tissue the SNR must be carefully monitored to avoid biased DTI indices, especially FA [6, 7]. The acquisition and analysis protocol was executed appropriately, and gave a “baseline” FA of 0.1 in the isotropic cortex and urinary tract tissue. The other results track qualitatively with other reports of medullary anisotropy, though the quantitative values differ [3-5]. This is the first report of 3T DTI of the kidney. This discrepancy may originate from insufficient SNR in other reports or the impact of smoothing or misregistration in this study. However, the spatial variation of the principal diffusion eigenvector in Figure 1 shows an excellent representation of local tubular orientation in the medullary compartments, which lends credence to accuracy of the overall scan. This study shows the FA and eigenvector orientation to have great potential as markers of renal function.

References

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