Diffusion tensor imaging and multiparametric mapping of experimental acute and chronic kidney disease at 7T

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Introduction:

Diffusion tensor imaging (DTI) is an emerging technique for acquisition of acute and chronic renal pathologies. Thus, DTI parameters fractional anisotropy (FA) and apparent diffusion coefficient (ADC) were decreased in early diabetic nephropathy [1], and cortical FA was found to be lower in patients suffering from chronic kidney disease as compared to healthy controls [2]. Here, in this multiparametric study DTI parameters, relaxation times (T1, T2, T2*) and kidney volume were acquired to diagnose acute and chronic kidney changes at 7 Tesla in experimental models *ex vivo*.

Material and Methods:

Acute kidney failure was induced in mice by withdrawing water access for 72 hours. Resulting from oral application of adenine, chronic interstitial nephritis was provoked in another mouse model. Following these protocols, mice with acute and chronic kidney disease as well as corresponding untreated controls were sacrificed and kidneys removed (acute kidney failure n=17 kidneys versus 12 controls; chronic nephritis n=16 kidneys versus n=15 controls).
A single-shot echo planar imaging (EPI) sequence with b: 0, 200, 400, 600, 1000 s/mm^2 and 256 diffusion directions was used to acquire ADC and FA maps on a 7 T ClinScan (Bruker, Ettlingen, Germany) (TR: 8 s, TE: 60 ms, in plane pixel size: 234 µm, slice thickness: 1 mm, bandwidth: 1860 Hz/pixel). Relaxation time maps for T1, T2 and T2* were calculated automatically by syngo software (Siemens, Erlangen, Germany; in plane pixel size = 52µm, slice thickness = 500 µm). Mean values of all parameters (ADC, FA, T1, T2, T2*) have been determined for 3 regions of interest (ROIs) placed manually in the upper, middle and lower part of the renal cortex (cor) as well as outer medulla (med). Additionally, volumetry of whole kidneys were performed on a T2 weighted turbo spin echo sequence. A wilcoxon-rank test was applied ($p < 0.05$ significant, $p < 0.01$ highly significant) for discrimination purposes between pathologic and control kidneys. Finally, tractography (Medical Imaging Tool Kit (MITK), FA_{min}: 0.05, tract $length_{min}$: 6 mm, seeds: 5) visualized tracts through renal pelvis, medulla and cortex within diseased and control kidneys.

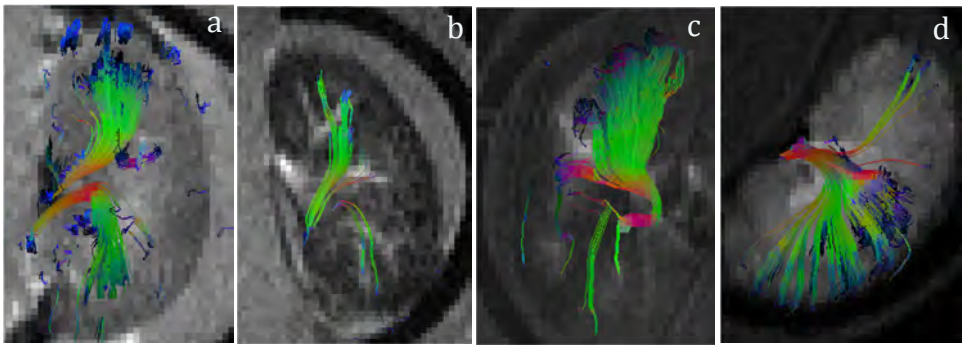

Fig.1: *Fiber tracking in murine kindeys.*
Rarefication of tracts in a dehydrated kidney (acute renal failure, b, n = 182 tracts) as compared to an untreated control (a, n = 1515 tracts). Tract reduction was most pronounced in the outer medulla and cortex of dehydrated kidneys.
Increased track number in a kidney with chronic nephritic changes (d, n = 1790 tracts), especially in the outer medulla and the cortex relative to a corresponding control (c, n = 733 tracts).

Results:

We observed a significant kidney volume loss and decreased values for $T1_{cor}$ and $T1_{med}$ ($p < 0.05$) in the acute model (renal failure) compared to controls. However, $T2_{cor}$, ADC_{med} and FA_{med} were even highly significantly ($p<0.01$) lower in kidneys after acute renal failure (median value of pathology versus control and standard deviation (95% confidence level): $T2_{cor}$ = 48±3ms – 55±4ms, ADC_{med} = $978±48\cdot10^{-6}$ mm^2/s – $910±36\cdot10^{-6}$ mm^2/s, FA_{med} = 0.11±0.02 – 0.23±0.05). Using tractography in representative kidneys, less tracts were found in dehydrated kidneys in comparison with controls, whereas a rarefication of tracts was localized particularly in the outer medulla. (Fig. 1 a and b).
Chronic interstitial nephritis resulted in volumetric augmentation (p=0.07). All other parameters were significantly or highly significantly increased ($T2_{cor}$ = 54±2ms – 46±1ms, $T2_{med}$ = 56±2 – 51±1ms, ADC_{cor} = $980±64\cdot10^{-6}$ mm^2/s – $687±105\cdot10^{-6}$ mm^2/s, ADC_{med} = $1139±53\cdot10^{-6}$ mm^2/s – $878±56\cdot10^{-6}$ mm^2/s und FA_{cor} (0.06±0.00 – 0.11±0.03) compared to the controls except for FA_{cor} that was decreased ($p<0.01$). Fiber tracking revealed a higher number of tracts in chronic nephritis compared to a control kidney (Fig 1 c and d).

Discussion:

DTI parameters FA and ADC allow for assessment of renal changes due to acute kidney failure and chronic interstitial nephritis. Multiparametric imaging including assessment of T1, T2 and T2* relaxation times as well as kidney volume further improve the diagnostic options for these diseases. Interestingly, DTI tractography might be a useful tool for assessment of renal tracts that differ distinctly between kidneys with acute and chronic pathologies, although histological correlation is still needed. In conclusion, ultra high field MRI including DTI and multiparametric mapping enables characterization and diagnosis of acute and chronic kidney changes in the presented experimental models.

References:

[1] Lu, Lan *et al.*; Use of Diffusion Tensor MRI to Identify Early Changes in Diabetic Nephropathy; Am J Nephrol, 2011; 34(5): 476–482.
[2] Liu, Zhiling et al.; Chronic kidney disease: pathological and functional assessment with diffusion tensor imaging at 3T MR; European Radiology, 2014; 0938-7994