Visualization of intrarenal water transport by diffusion tensor tractography

M. Pedersen[1], A. B. Lødrup[1], K. Karstoft[1], E. A. Nielsen[2], M. K. Hagensen[2], P. A. Nielsen[2], A. Stavropoulos[3], B. Jespersen[4], S. Ringgaard[1], and M. Smerup[2]

[1]MR Research Center, Aarhus University Hosptial, Aarhus, Denmark, [2]Institute of Clinical Medicine, Aarhus University Hosptial, Aarhus, Denmark, [3]Dept. of Periodontology, Aarhus University, Aarhus, Denmark, [4]Department of Nephrology, Aarhus University Hospital, Aarhus, Denmark

Introduction

Diffusion tensor imaging (DTI) of kidneys has shown that the tubular water diffusion is highly anisotropic [1], which is explained by the fact that water transport is a predominant phenomenon throughout the kidney due to the kidney's major role in either solute reabsorption or excretion. These movements are mainly located in the tubular cells and are controlled either by active or passive mechanisms, depending on their location in the nephrons. This organized structure has recently been investigated by DTI, where three-dimensional tractography was used to visualize the complex water transport in the renal medulla [2]. The aim of this study is to investigate if DTI can be used for imaging the principal route of free water in the kidney, and we hypothesize that this route can act as an indirect representation of the segments of nephrons going centripetally from the renal parenchyma to the collecting ducts.

Methods

This study included Danish Landrace pigs with mean weight of 40 kg (n=6; 12 kidneys). After intubation and connected to a respirator, anaesthesia was maintained with isofluran mixed. The pigs were allowed to rest while hydration was maintained by iv infusion of saline. Nephrectomy was performed, and the renal arteries and veins were ligated and cut through. The kidneys were removed and brought to a fume cupboard, where a catheter was placed in the remaining part of the renal artery. The kidney was flushed with 200 ml phosphate buffer to wash out coagulated blood and perfused using a peristaltic pump with phosphate-buffered formaldehyde 4% for 5 min at a rate of 250 ml/min. Following perfusion-fixation, the kidney was immersed in the same fixative. The fixated kidneys were warmed to room temperature and MRI examinations were performed with a Philips 1.5 T clinical system. The kidney was placed in the magnet oriented with the long axis (upper to lower pole) parallel to the axis of the main magnetic field, and a surface RF-coil was used for data reception. After scout imaging, a DTI sequence was applied as a multi-slice (30-40 slices) 2D spin echo sequence using the following parameters: slice thickness = 1.3 mm, field-of-view = 170x101 mm^2, matrix = 128x76 (isotropic resolution of 1.3 mm^3), TR = 3900 ms, and TE = 72 ms. We acquired 32 diffusion sensitive images with b=1271 s/mm^2 and 1 image with b=0 s/mm^2. The total scan time was 11 hours. After MRI, the kidney was immersed in PBS solution, and stored at 4 ˚C prior to histological examination. Acquired data were processed using home-made software. We used a custom-made algorithm to track the connections of the intratubular segments in order to track the nephron "path". A number of voxels of interest are selected from the total three-dimensional matrix. Based upon the characteristics of the primary eigenvectors of all voxels in the total matrix, the algorithm then calculates any possible "track", or "pathway", which passes through the chosen voxel of interest. The paths were color-coded to clearly visualize the direction of tracks.

Results

The porcine kidney resembles the best approach to investigate renal effects in human; though some overall anatomical differences exist between the two species (Fig 1A). In all animals, cortex and medulla could be well differentiated using the calculated fractional anisotrophy image (Fig 1B). The orientation of medullary diffusion anisotrophy was visualized using tractography (Fig 1C) and color-coded to orientation maps. No specific tracks could be found in the renal cortex. A zoomed image of the calculated tracks allows a better overview of regional tracks, for example the complex set of rays shown in the upper pole (Fig 1D).

Discussion:

The found high anisotophy is likely explained by the radial organization of tubules and the collecting ducts, draining into the pelvis. Further studies using ex vivo histology are warranted to confirm this explanation, and our findings will be followed by DTI studies in clinically relevant diseased models, where water reabsorption or drainage are hindered.

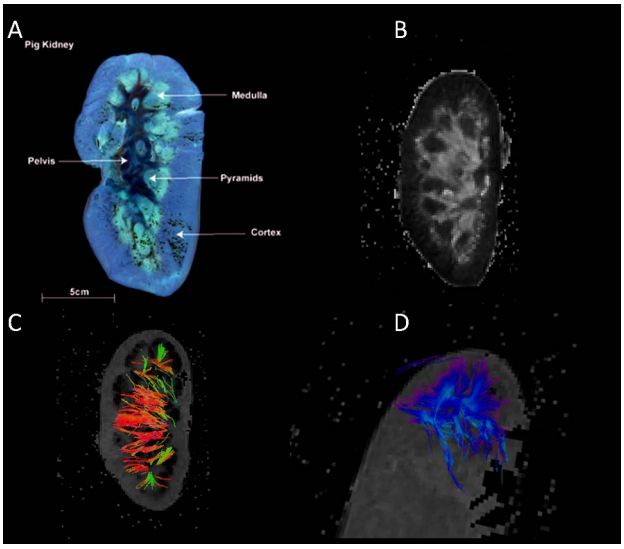

Figure 1: Morphological (ex-vivo) image of pig kidney (A), calculated fractional anisotrophy image (B), DTI-based fibertracking (C), and high-resolution images of fibres in the upper pole (D).

References

1. Ries et al. Diffusion tensor MRI of the human kidney. J Magn Reson Imaging 14 (1), 2001, 42-49.
2. 2. Notohamiprodjo M, et al. Diffusion tensor imaging of the kidney with parallel imaging: initial clinical experience. Invest Radiol. 43(10), 2008, 677-85.