IN VIVO FUNCTIONAL SODIUM MR IMAGING OF THE HUMAN KIDNEYS AT 7 TESLA

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TARGET AUDIENCE: Abdominal radiologists, physicists interested in sodium MRI, physicists developing sequences for fast relaxing tissues.

PURPOSE: Renal MRI now reaches beyond morphology and aims to asses functional parameters, such as sodium (^{23}Na) corticomedullary gradients [1-3], which seems to reflect parts of the urinary concentration mechanism. The main challenge for *in-vivo* ^{23}Na MRI of the kidneys is to obtain images with sufficient signal-to-noise ratio (SNR). Although ^{23}Na MRI of cartilage has already demonstrated 2.3-fold higher SNR at 7T compared to 3T, the feasibility of ^{23}Na MRI in human kidneys at 7.0T has not been shown as yet. Therefore the aim of this study was to demonstrate the feasibility of ^{23}Na MRI of the human kidneys at 7T with an improved spatial resolution and to verify the concept of an increasing cortico-medullary gradient.

METHODS: This study was approved by the local ethics committee and informed written consent was obtained from all participants. Eight healthy volunteers (4 female, 4 male) with a mean age of 29.4±3.6 (mean ± standard deviation) years (range: 24.5-33.5 years) and a mean body-mass-index of 21.7±2.6 kg/m^2 (range: 19.5-27.5 kg/m^2) were included in this study. The volunteers were asked to abstain from water intake within 60 minutes before the examination. No other restrictions on food and water intake were applied. All volunteers were scanned with a 7T whole body system (Magnetom, Siemens Healthcare, Erlangen, Germany) using a six-channel ^{23}Na-only spine-array coil (Quality Electrodynamics, Mayfield Village, Ohio, USA). To maximize SNR in the kidneys, a series of 3D gradient echo scans with a variable echo time scheme (vTE-GRE) [4] was measured using different pulse amplitudes (140-220V), the minimal TR (31-64 ms restricted by specific absorption rate limits) and the number of averages that resulted in a measurement time of ~2:40 min per scan. For each volunteer, the optimal combination of pulse amplitude and TR was defined as scan with the highest SNR in the kidneys. To assess the corticomedullary gradient, vTE-GRE was used: resolution= 4x4x5 mm^3; 24 slices; TE= 4.19 ms; mean TR= 49 ms (range: 38-61 ms); bandwidth= 30 Hz/pixel; mean number of averages= 34 (range: 28-42); mean measurement time of about 42 minutes (Fig.1B). To correct vTE-GRE images for the inhomogeneous sensitivity of the spine coil, phantom images were also acquired. Corrected vTE-GRE images were obtained by multiplying the original image by the correction matrix from phantom measurements using IDL (Research Systems Inc, Boulder, CO, USA) and Matlab (Mathworks, Natick, MA, USA). The corrected data sets were angled and the corticomedullary gradient was evaluated in OsiriX (OsiriX Foundation, Geneva, Switzerland). Three linear regions-of-interest (ROI) with a length of 20 mm (6 pixels) were placed in the caudal, middle and cranial part of each kidney, totaling 144 measurements (Fig.1B). The signal-to-noise ratio (SNR) values for each pixel in linear ROIs were calculated as signal intensity divided by the standard deviation of an ROI from a signal-free area. For more accurate comparison of corticomedullary gradients between volunteers, normalized ^{23}Na signal intensities (SI_{norm}) were calculated for all pixels in linear ROIs. All SI values in one linear ROI were divided by the maximum SI from this ROI and multiplied by 100 to obtain SI_{norm} in percentages. The mean slope of the cortico-medullary gradient was calculated from the first four pixels as a first-order fit for each healthy volunteer and as an overall mean.[3] Maximum differences between the cortical and the medullary ^{23}Na SNR were calculated. Statistical analyses were performed in MedCalc (MedCalc Software, Mariakerke, Belgium).

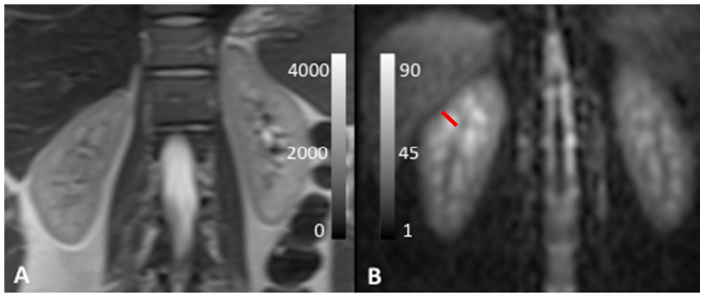

Fig.1: A. coronal T2-weighted image acquired only from one healthy volunteer at 3T for comparison with the corresponding **B.** coronal ^{23}Na SNR map where the red line represents an ROI evaluation of the corticomedullary gradient.

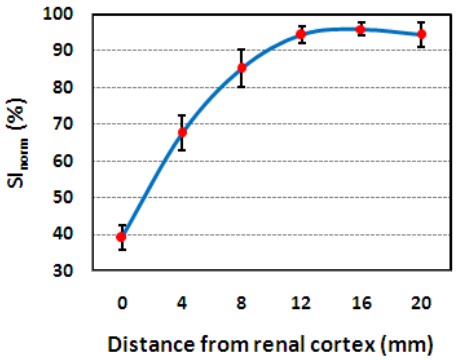

Fig .2: The cortico-medullary gradient of ^{23}Na SI_{norm} as mean and standard deviation for all healthy volunteers.

RESULTS: As an overall mean, the slope of the cortico-medullary gradient was 4.1±1.0, ranging inter-individually from 2.7 to 5.3. The mean corticomedullary ^{23}Na SNR from all volunteers increased from the renal cortex (34.1±10.2) towards the medullary pyramid (89.2±18.7). The maximum increase in the cortico-medullary ^{23}Na SNR ranged inter-individually from 52.3% to 65.7%, with a mean of 60.7%. The average SI_{norm} values ranged from 39.1%±3.4% to 96.0%±1.7%. The mean corticomedullary gradient from mean SI_{norm} values is presented in Fig.2.

DISCUSSION: Compared to previous human kidney studies with nominal voxel sizes of 0.135 mL [1,2] or 0.125 mL [3] at 3T, the nominal voxel size was decreased to 0.080 mL and the image quality was improved in this initial 7T study. A steeper slope for the corticomedullary gradient was observed at 7T (mean slope: 4.1±1.0) when compared to 3T (mean slope: 3.38±0.35).[3] Previous results showed inter-individual differences in the gradient slopes and a dependency of gradient slope on water intake[3]. The steeper slope and its relatively high standard deviation in this study could be attributed to the short time of the food and water restrictions.

CONCLUSION: This study showed for the first time the feasibility of *in vivo* ^{23}Na MRI of the human kidneys at 7T using the vTE-GRE approach. In addition, the presence of a corticomedullary gradient from the renal cortex in the direction of the medullary pyramid was confirmed at 7T.

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