In vivo sodium (^{23}Na) MRI of the human kidneys after water deprivation at 7 Tesla

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TARGET AUDIENCE: Scientists and physicians interested in ^{23}Na MRI of the human kidneys.

PURPOSE: This study aims to investigate the sodium (^{23}Na) concentration gradient in the kidney[1,2] (from the cortex to the medulla) at B_0 = 7 Tesla. ^{23}Na MRI highly benefits from higher magnetic field strength B_0 [3]. Up to now, only a few ^{23}Na MRI studies of the human torso have been performed at 7 T [4,5]. Besides the inherently low signal-to-noise ratio (SNR), respiratory motion additionally complicates abdominal sodium image acquisition[6]. Since sodium ions play an important role in regulatory homeostatic functions of the human kidneys, ^{23}Na MRI can provide valuable information concerning renal function, especially in nephropathy, renal failure, and kidney transplantation[7,8]. Here, *in vivo* renal ^{23}Na signal distribution is examined for a healthy volunteer that was examined after 12 h of water deprivation. Hereby an increased concentration gradient from renal cortex to hyper intense medulla was induced.

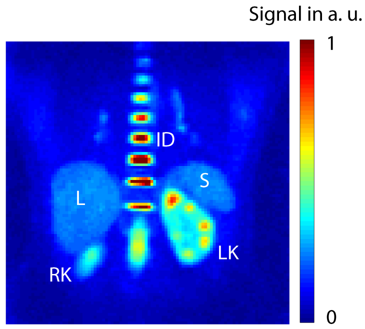

Fig. 1: ^{23}Na abdominal signal distribution in coronal slice (RK/LK: right/left kidney, L: liver, S: stomach, ID: Intervertebral disks).

METHODS: All measurements were performed on a 7 T whole body MR system (MAGNETOM 7 T; Siemens Healthcare, Erlangen, Germany) using a close-fitting oval-shaped ^{23}Na body resonator[6] (f_0 = 78.6 MHz, dimensions: major axis a = 420 mm, minor axis b = 315 mm, length z = 350 mm). *In vivo* measurements were performed using a density-adapted 3D radial sequence (DA-3DPR)[9] and a golden angle distribution of projections[10]. The acquired full dataset was divided into two motion separated subsets (exhaled, inhaled) by evaluating the signal at k-space center[6]. In this study the investigations were performed on the exhaled images to reduce motion blurring[6].

<u>Sequence parameters DA-3DPR</u>: t_{pulse} = 1.5 ms, α = 44°, T_E = 0.85 ms, T_R = 20 ms, short-term averaging n_{avg} = 5, number of projections = 18,200, T_{AQ} = 30 min 20 s, nominal isotropic spatial resolution = (3.5 mm)^3, reconstructed FOV = (350 mm)^3.

Image reconstruction was performed with MATLAB (The MathWorks Inc., Natick, MA, USA). Motion separation results in an undersampling factor of about 3.5. An iterative reconstruction was applied to reduce image noise[11]. For quantitative ^{23}Na MRI the ^{23}Na signal distribution was converted into a concentration map using an internal reference (blood of the heart with 79 mM [12]). Transmit and receive field distributions were assumed to be homogeneous due to low variations in these distributions in earlier phantom measurements[6]. The cortico medullary gradient was investigated by analyzing the increase in sodium concentration from cortex to medulla[1].

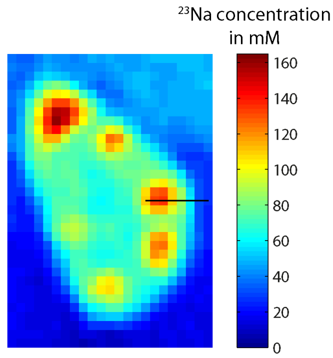

Fig. 2: ^{23}Na concentration map for left kidney. Cortico medullary gradient is determined along the illustrated black line.

RESULTS: Figure 1 displays a coronal slice showing the ^{23}Na signal distribution of the abdomen and the lungs. The zoomed-in region of the left kidney (Figure 2) shows the resulting concentration map with increased ^{23}Na concentrations in the renal medulla after water deprivation. Figure 3 is showing an exemplary cortico medullary gradient resulting from a line plot (black line Figure 2). The ^{23}Na concentrations at the tip of the medulla and at the edge of the cortex were estimated to 136 mM and 32 mM and the resulting ratio between these two concentrations was 4.3.

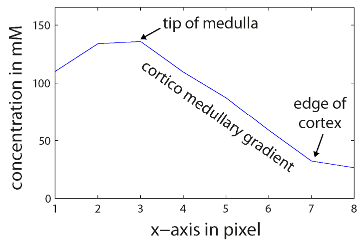

Fig. 3: Exemplary line plot determined along the black line in Figure 2 showing the cortico medullary gradient.

DISCUSSION & CONCLUSION: Sodium signal distribution in the left kidney after water deprivation shows the expected characteristics with high values in the medulla and low values in the cortex. Image quality benefits from the high magnetic field of B_0 = 7 Tesla and from the high nominal isotropic spatial resolution of (3.5 mm)^3. The individual medullae are better delineated in comparison to the results published earlier at 3 Tesla with resolutions of (5 mm)^3 and 3 mm x 3 mm x 15 mm [1,2]. As in the work of Maril *et al.*[1] the cortico medullary concentration gradient shows a linear signal course over a distance of 14 mm. In the present work, the ratio between the tip of the medulla and the cortex edge is slightly lower compared to the value of 4.75 of Maril *et al.* [1].

The high isotropic nominal resolution of (3.5 mm)^3 and the high field strength may enable a more precise determination of the cortico medullary gradient in future studies at 7 T for a group of volunteers. Furthermore, the influence of transmit and receive field distributions should be further investigated. These ^{23}Na abdominal images obtained at 7 T indicate that ^{23}Na MRI at higher field strengths can be a valuable tool to characterize physiological changes due to different physiologic conditions or due to pathologies.

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