

Sodium MR imaging of human kidney using a dual-tuned ($^{23}\text{Na}/^1\text{H}$) body RF coil at 3T: quantitative assessment of sodium concentration and corticomedullary gradient in healthy subjects

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Introduction: Kidney functionality (concentration of urine and maintenance of homeostasis of fluids and electrolytes) depends on the maintenance of the corticomedullary sodium gradient, produced by active reabsorption of sodium by ion pumps in the medulla (countercurrent system). Sodium MR imaging can visualize the distribution of sodium concentration in human kidney in vivo [1, 2], and therefore is a potential non-invasive biomarker to assess renal function. Quantitative assessment of sodium concentration (SC) and corticomedullary sodium gradient in normal kidney is required for further comparison with renal pathologies. Therefore, the purpose of our study was to quantitatively assess sodium concentration and the corticomedullary sodium gradient in healthy human kidneys using a dual-tuned (DT) RF kidney coil at 3T scanner.

Materials and Methods: Four healthy male subjects (mean age, 32 years) were enrolled in this IRB approved study. All imaging was performed using a 3T scanner (Siemens Medical System, Erlangen, Germany) with an in-house DT RF kidney coil. Two-channel quadrature proton and sodium coils were built in a half pipe (diameter 300 mm); each channel loop was designed in saddle shape (Fig. 1). A 90° phase shifter for both nuclei coil was added to circularly polarize B_1 RF field to gain SNR by $\sqrt{2}$. Reflection and transmission coefficients were < -17 dB. Six 4% agarose (co-registration) markers with 70 mM [^{23}Na] were positioned on the coil frame. Subjects were in the prone position with the DT coil center co-aligned with the left kidney. Proton anatomical imaging was obtained using multi-slice 2D GRE (TR/TE = 300/5 ms, resolution = 1.6×1.6 mm², slice thickness = 2 - 3 mm) during breath-holding. Sodium MR imaging was obtained using the same shimming as the proton imaging and 3D ultra-short echo time spiral sequence [3]: RF hard pulse 500 μ s; TR/TE = 100/0.27 ms; readout time = ~15 ms; resolution = 3 mm³; and total acquisition time = 27 min. For the quantification of renal sodium concentration, B_1 field inhomogeneity was corrected on the basis of sodium images of a homogeneous phantom (60-mM [^{23}Na] saline). Sodium signal decay in kidney imaging due to T_1 and T_2 relaxation time was compensated based on 4% agar with 153-mM [^{23}Na] (17.6 ms and 9.7 ms, respectively). Measurements were performed on sodium images of the left kidney in the coronal plane. The mean sodium concentrations of cortex and medulla were measured with nine corresponding ROIs (area 30 mm²). Spatial variation of the sodium concentration was also measured in pixel-by-pixel along the corticomedullary axis as previously described [1-2]. Corticomedullary sodium gradient was calculated as: (i) ratio of the mean sodium concentration of the medulla over that of the cortex; (ii) ratio of the maximum sodium concentration of the medulla over the minimal sodium concentration of the cortex edge; and (iii) the normalized slope of sodium concentration, that is, $(SC_{\text{medulla}} - SC_{\text{cortex}})/L_{\text{m-c}} \cdot (\text{mean SC}) \cdot 145$ mM.

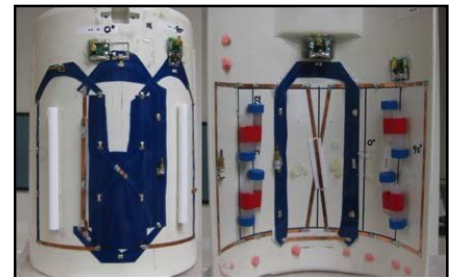


Fig.1 Dual ($^1\text{H}/^{23}\text{Na}$)-tuned RF coil – saddle coil (yellow, 300mm*180mm) with single loop (green, 100m*200mm)

Results and Discussion: In each subject, sodium images allowed clear zonal demarcation of medulla versus cortex (Fig. 2). The mean sodium concentration measured 79.3 ± 15.2 mM in the cortex and 180.5 ± 31.6 mM in the medulla, resulting in the mean ratio of 2.3 ± 0.2 ($N = 4$). Sodium signal increased linearly ($R=0.997$, $P<0.05$) from cortex to medulla (Fig. 3), and the ratio of sodium concentration at medulla papilla vs. that at cortex edge was 3.0 ± 0.1 ($N = 4$), which is similar to values reported in a previous study [1]. In addition, the mean slope of sodium concentration measured 10.4 ± 0.9 mM/mm ($N = 4$). In conclusion, we obtained consistent and reproducible measurements of corticomedullary sodium gradient in 4 healthy subjects. Non-invasive monitoring of corticomedullary sodium gradient may serve as an early indicator of kidney disease in both native and transplanted kidneys (e.g., acute tubular necrosis or acute rejection). The results of our study will be used as the benchmark for future studies focused on alterations in renal physiology and function.

References: 1, Maril N, et al, MRM 56:1229-34 (2006). 2, Rosen, Y, et al, Acad Radiol 16:886-9 (2009). 3, Zhao et al, ISMRM (2009). 4, Maril N, et al, Kidney International 69:768-68 (2006).

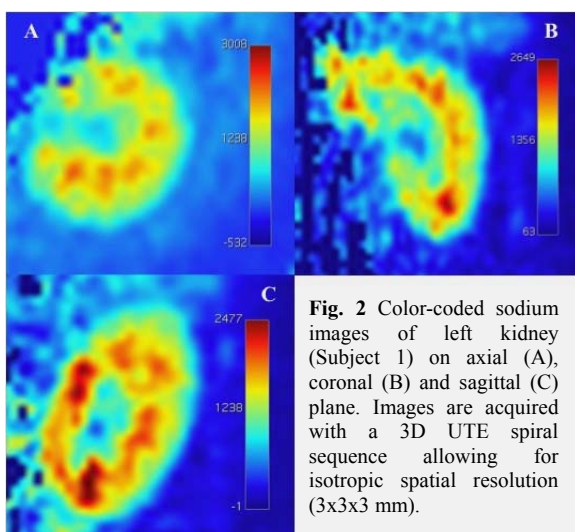


Fig. 2 Color-coded sodium images of left kidney (Subject 1) on axial (A), coronal (B) and sagittal (C) plane. Images are acquired with a 3D UTE spiral sequence allowing for isotropic spatial resolution (3x3x3 mm).

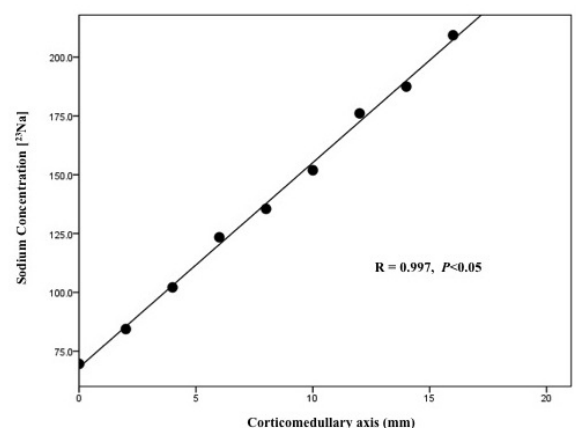


Fig. 3 Mean plot of sodium concentration along corticomedullary axis