^{23}Na/^{1}H *In-Vivo* Renal MRI of Rodent Kidney at 3T by using a Double-Tuned Transceiver Resonator System

Raffi Kalayciyan[1], Matthias Malzacher[1], Sabine Neudecker[2], Norbert Gretz[2], and Lothar R. Schad[1]

[1]*Computer Assisted Clinical Medicine, Heidelberg University, Mannheim, Germany,* [2]*Medical Research Center, Heidelberg University, Mannheim, Germany*

Introduction:

^{23}Na-MRI at high-field strengths (>3T) has proven to be a unique modality for monitoring renal function non-invasively after pharmacological interventions in animal models [1-2]. Nevertheless, performing *in-vivo* studies on clinical MR-systems simplifies transferring newly-developed ^{23}Na-MRI methods to clinical diagnostic imaging, although the lower field strengths represent a major drawback.

The aim of this work was to demonstrate the feasibility of *in-vivo* ^{23}Na-MRI with optimized signal sensitivity at 3T. For this purpose, a double-tuned transceiver RF resonator system was developed, which allowed for ^{1}H and ^{23}Na MR signal detection from both kidneys without the need for replacing the coil system. Furthermore, an RF interface was integrated for splitting of the transceiver power and switching between receive and transmit modes. Finally, the resonator system was evaluated by monitoring furosemide-induced temporal ^{23}Na signal changes in the medulla and cortex with sufficient spatial and temporal resolution at 3T.

Methods:

The resonator system used for bilateral ^{23}Na/^{1}H-MRI of kidney was a double-tuned transceiver (TXRX) surface coil which was saddle-shaped in order to maximize the measured signal sensitivity in kidneys (see Fig. 4). The ^{1}H frequency (123.2 MHz) was tuned by the fixed-value capacitors (C_H1 and C_H2) and the tuning trap circuit composed of C_trap and L_trap. The ^{1}H matching was achieved through a trimmer capacitor (C_match_H). The ^{23}Na RF path included a ^{1}H trap circuit composed of L_block and C_block, which eliminated the ^{1}H signal and allowed for matching using a series variable capacitor (C_match_Na). At the higher ^{1}H frequency of 123.2 MHz the ^{23}Na capacitors C_Na1 and C_Na2 posed low impedances and the capacitors behaved like a short circuit. For tuning of ^{23}Na resonance circuit at 32.586 MHz, a tuning trimmer capacitor (C_tune_Na) was mounted in parallel to the C_Na1 and C_Na_2 (see Fig. 1). For balancing purposes, the resonance circuit was designed with split fixed value capacitors. Remotely variable matching and tuning was achieved on a circuit board to which the resonance coil was connected. The Q-factor ratio of unloaded to loaded was measured to be 216/146 for ^{23}Na-channel and 229/173 for ^{1}H-channel. A homogeneous phantom containing 0.9% NaCl-solution was used to acquire sensitivity profile of the both channels (Fig. 3a-b).

The custom-built RF coil interface (STARK CONTRAST, Erlangen, Germany) is composed of a frequency power splitter, a ^{1}H switch between linear transmit and receive modes, and a ^{23}Na switch between linear or quadrature transmit and receive modes including a phase-shifter (Fig. 2a). In this study, the ^{1}H and ^{23}Na signals were generated and acquired in linear mode. The ^{23}Na/^{1}H TXRX RF resonator (Fig. 2b,c) was connected to the linear ports of the RF coil interface and then, it was connected to the scanner.

Furosemide is a loop diuretic which reduces NaCl reabsorption in the loop of Henle. Hence, the corticomedullary osmotic gradient is abolished resulting in reduced medullary ^{23}Na signal and increased urine production. ^{23}Na-Kidney-MRI was used to monitor the spatial changes in ^{23}Na after diuretics administration.

The ^{23}Na-MR measurements were performed on a 3T Magnetom TIM Trio system (Siemens, Erlangen). A 3D density adapted radial sequence [3] was adjusted for short TE (0.5ms) with 1.5mm³ nominal voxel resolution, TR=57ms, 10min acquisition time, and 60Hz/pixel bandwidth. The ^{1}H reference image was acquired prior to ^{23}Na scanning using a 3D VIBE sequence with TE/TR = 2.4ms/10ms, and a resolution of 0.5 x 0.5 x 1 mm^3. The ^{23}Na measurements took about 50 min with a scan time of 10 min each. A bolus of furosemide (10 ml/kg body weight) was administered intravenously in a Wistar rat (300 g) after the first ^{23}Na MR-image. ^{23}Na scans were performed for up to 40 min after bolus injection.

Results:

The MR signal sensitivity profile of the ^{23}Na/^{1}H TXRX resonator was demonstrated using a homogeneous phantom of 5cm diameter filled with 0.9% NaCl solution (Fig. 3a,b). The abdominal ^{1}H MR image showing both kidneys in a transaxial slice is presented in Fig. 3 c. The co-registered ^{23}Na-MR images prior to and after furosemide injection are shown for every 10 min of acquisition period in Fig. 4. The characteristic decrease in the ^{23}Na signal within the inner medulla of both kidneys after furosemide injection was measured to be about -50±2%. In the cortical medullar tissue the ^{23}Na signal was increased about +37±12%. These values are in good agreement with the recently published values [1].

Discussion and Conclusion:

The newly-developed transceiver resonator system allowed for acquiring ^{1}H and ^{23}Na images without the need to exchange resonators inbetween the ^{1}H and ^{23}Na scans. Furthermore, the dual-tuned resonator system solved the issue of missing shimming for the single-tuned X-nuclei MR resonators on human scanners. The shimming could now be effectively performed on ^{1}H signal to achieve a homogeneous B_0 field – a necessary condition for ^{23}Na MRI. The integration of the hardware using a TXRX RF interface will be a possibility for future multinuclear MRI applications in preclinical, as well as in clinical use.

The short TE (<500µs) and sensitivity-optimized surface resonator enabled fast acquisition of ^{23}Na kidney images within 10min per scan, which allowed to study the fast ^{23}Na change after furosemide injection. The decrease in medulla and increase in cortex has been measured before and the herein reported values matched to those in the literature exceptionally well. In conclusion, the preclinical renal MR investigation on a human scanner was demonstrated to be feasible despite the field strength penalty. Further measurements are needed to determine the accuracy of ^{23}Na MR measurements in the renal tissue, and to establish this powerful imaging technique for absolute quantification of the sodium concentration.

References: [1] Maril et al., Kidney Int. 55:545-552 (2005). [2] Neuberger et al., MRM 58(5):1067-71 (2007); [3] Nagel *et al.*, MRM 62, 1565-1573 (2009).

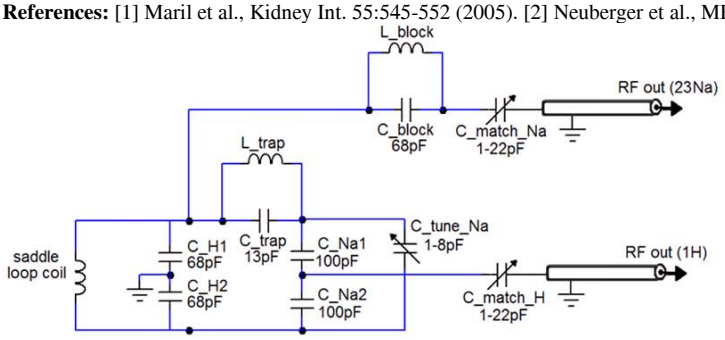

Fig. 1 – Electrical circuit diagram of the double-tuned (^{23}Na/^{1}H) transceiver resonator.

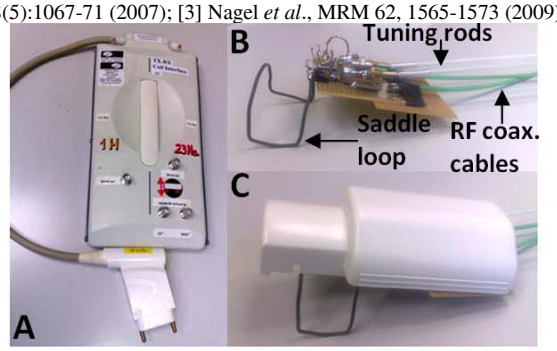

Fig. 2 – (a) The RF interface with ^{1}H linear and ^{23}Na quadrature transceiver switch, and (b) the double-tuned TXRX resonator (c) in fiber glass housing.

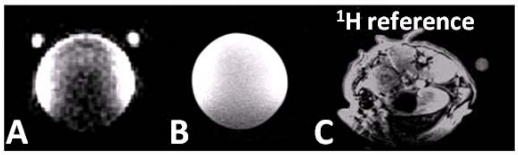

Fig. 3 – (a) The ^{23}Na and (b) ^{1}H sensitivity profile of the TXRX resonator compared to ^{1}H transaxial cross-section of rodent abdomen acquired by the 3D VIBE imaging sequence.

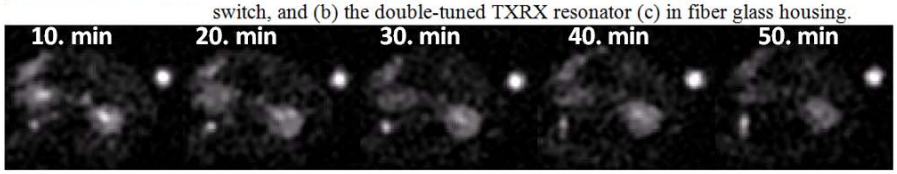

Fig. 4 – The ^{23}Na rodent kidney MR images acquired every 10 min. Furosemide was injected after 10 min.