

A dual resonator system for whole-body sodium-MRI at 3T

F. Wetterling¹, A. Rennings², R. Kalayciyan¹, D. M. Corteville¹, S. Konstandin¹, and L. R. Schad¹

¹Computer Assisted Clinical Medicine, Heidelberg University, Mannheim, Germany, ²General and Theoretical Electrical Engineering, University of Duisburg-Essen, Duisburg, Germany

INTRODUCTION: ²³Na-MRI (Na-MRI) can provide unique and direct information about the tissue viability after stroke [1], and the integrity of tumor tissue [2]. Nevertheless, clinical routine use of Na-MRI techniques is mostly hindered by the required specialized resonator systems. Especially the lack of available homogeneous B₁-field excitation at the ²³Na frequency limits the day to day use of these novel techniques. The helmholtz design has been normally used to homogenize the ²³Na B₁-field for human Na-MRI in recent years [3-5], although the B₁-field homogeneity and reproducibility can be further improved through volume resonator designs. The benefits for ¹²⁹Xe [6], and ³He MRI of the human lungs [7,8] at 1.5T had been demonstrated by others. Furthermore, high SNR and maximum B₁-homogeneity can be achieved with dual resonator system [9]. The aim of this study was to test and integrate the first ²³Na whole body resonator on a clinical 3T system and show its advantages over common resonator approaches as a stand-alone transceiver coil and as a transmit-only resonator in conjunction with a ²³Na receive-only surface coil.

METHODS: The newly-developed ²³Na dual resonator system (STARK CONTRAST, MRI Coils Research, Erlangen, Germany) is presented in Figure 1. The whole-body resonator was designed as a 16 leg asymmetric birdcage structure (47.4cm horizontal, and 35cm vertical diameter, 50cm length), which generated circularly polarized B₁-field in the xy-plane. A transmit-receive switch enabled to use the coil in transceiver mode, and active decoupling allowed to use the same resonance structure together with a surface coil (Figure 1). The resonator could also be split for patient positioning purposes. Initial evaluation of the coil system comprised B₁-field simulations (see figure 2) with MoM software by FEKO (EM Software & Systems GmbH, Böblingen, Germany). A 3D density adapted radial sequence [10] was adjusted for short TE (0.5ms) ²³Na-MRI with 6 x 6 x 6 mm³ voxel resolution, TR = 49 ms, 1ms block pulse, 60° flip angle, 10 min acquisition time, and 60Hz/pixel bandwidth. In a first experiment, the entire body of a male human subject was scanned in five segments of firstly the head and shoulder, secondly the upper body, thirdly the lower body, fourthly the knees and thighs, and fifthly the calves and feet. In a second experiment, a 20-cm inner diameter circular surface coil with active and passive decoupling was added to the coil set-up to be used in receive-only mode (inset in figure 1). The sensitivity of the newly-developed resonator system was compared to a double-tuned ¹H/²³Na quadrature head coil (27cm inner diameter, 30cm length, RAPID Biomedical, Rimpf, Germany) in phantom images of a standard bottle filled with 5g/l NaCl solution and in head images of a male human in supine (¹H/²³Na head coil) and prone positioning (²³Na dual resonator system), respectively.

RESULTS and DISCUSSION: The B₁-homogeneity was measured to be better than ±5% within 66% of the inner coil volume – a value deemed to be excellent when considering the asymmetric and hence complex birdcage design. Excellent B₁-field homogeneity and receive sensitivity is furthermore evident from the first ever acquired whole body ²³Na image of a human male person (figure 3). Similar X-nuclei body resonator has never been used at 3T before. For whole body scanning the body resonator was placed on the patient table, which required repositioning of the patient after each of the five segment scans. Integrating the ²³Na body resonator in the scanner's housing could enable whole body imaging without the need to repositioning patient between scans. This option could potentially be interesting for ultra high field applications where ¹H body resonators cannot be used anymore, which could however be replaced by a ²³Na body resonator. Improved whole body ²³Na image quality could thus be achieved by the inherently higher polarization at the B₀ field strength in addition to avoiding co-registration artifacts through moving the patient table after each segment. The reference voltage for a 180° block pulse of 1ms length was measured to be 180V for the head coil and 1200V for the whole body resonator. Available 390V maximum magnitude provided by X-nuclei power amplifier therefore generated 60° flip angle for 1ms block pulse – an acceptable trade-off allowing for as low TE as 0.5ms. Furthermore, shielding of the body resonator was required to limit coupling of the ²³Na resonator with the ¹H body resonator of the 3T MRI system. Therefore, the basic frequency and manual shimming was adjusted via the ²³Na channel. Compared to the ¹H/²³Na transceiver head coil the SNR increase was measured to be ~80 - 100% near the surface coil in phantom and in *in vivo* scans (see figure 4). The reproducible B₁-homogeneity of developed birdcage coil and achieved high SNR with the single loop surface coil will enable accurate ²³Na quantification in for instance the human kidney, heart, brain, and knee. This is the first time that an X-nuclei MR image of the entire human body is presented. Future applications may involve non-invasive whole-body monitoring of treated tumor tissue in order to assess tissue viability and integrity changes after chemo- and radiotherapy. In conclusion, physically separating the body resonator from the receiver coil enabled to generate a reproducibly homogeneous B₁-field over a large volume while application of organ-specific ²³Na receive-only resonators enables to maximize the detectable SNR.

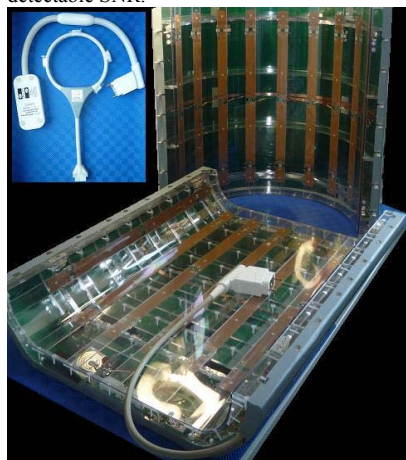


Figure 1: ²³Na asymmetric birdcage resonator and receive-only surface coil with preamplifier-holding adapter box (inset).

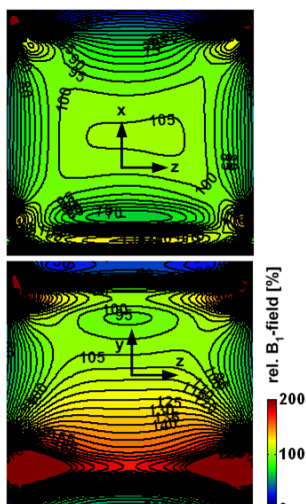


Figure 2: simulated B₁-field maps for asymmetric birdcage coil in xz- (top) and yz-view (bottom). Figure 3: sagittal and coronal ²³Na-images [a.u.] of the entire human body.

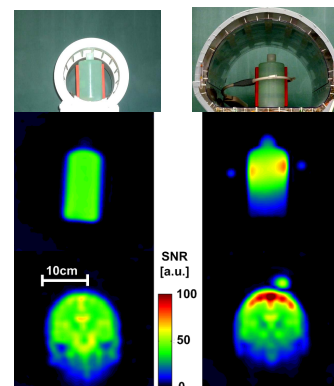
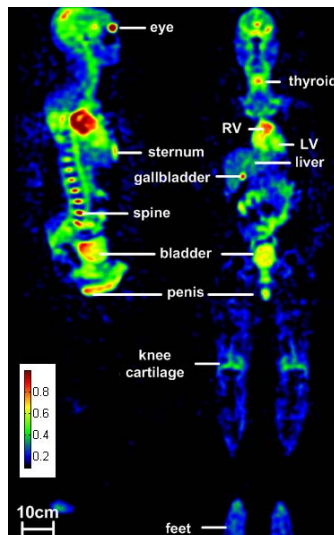


Figure 4: photographs of a) ¹H/²³Na quadrature birdcage (TXRX, left column) and b) dual resonator system (TORO, right column) and SNR maps of a phantom filled with 100mM NaCl (middle row) and a human head (lower row).

REFERENCES: [1] Wetterling *et al.*, Proc. ISMRM 18, Stockholm, 680 (2010); [2] Ouwkerk *et al.*, Breast Cancer Res Treat (2007); [3] Steidle *et al.*, Magn Res Imag (2004); [4] Lanz *et al.*, Proc. ISMRM 15, Berlin, 241 (2007); [5] James *et al.*, Proc. ISMRM 16, Toronto, 615 (2008); [6] Pura *et al.*, Proc. ISMRM 18, Stockholm, 4600 (2010); [7] de Zanche *et al.*, MRM 60, 431-438 (2008); [8] Deppe *et al.*, Proc. ISMRM 18, Stockholm, 3838 (2010); [9] Wetterling *et al.*, PMB (2010); [10] Nagel *et al.*, MRM 62, 1565-1573 (2009)