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

F. Wetterling[1], A. Rennings[2], R. Kalayciyan[1], D. M. Corteville[1], S. Konstandin[1], and L. R. Schad[1]
[1]Computer Assisted Clinical Medicine, Heidelberg University, Mannheim, Germany, [2]General and Theoretical Electrical Engineering, University of Duisburg-Essen, Duisburg, Germany

INTRODUCTION: ^{23}Na-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 B_1-field excitation at the ^{23}Na frequency limits the day to day use of these novel techniques. The helmholtz design has been normally used to homogenize the ^{23}Na B_1-field for human Na-MRI in recent years [3-5], although the B_1-field homogeneity and reproducibility can be further improved through volume resonator designs. The benefits for ^{129}Xe [6], and ^{3}He MRI of the human lungs [7,8] at 1.5T had been demonstrated by others. Furthermore, high SNR and maximum B_1-homogeneity can be achieved with dual resonator system [9]. The aim of this study was to test and integrate the first ^{23}Na 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 ^{23}Na receive-only surface coil.

METHODS: The newly-developed ^{23}Na 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 B_1-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 B_1-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) ^{23}Na-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 ^{1}H/^{23}Na quadrature head coil (27cm inner diameter, 30cm length, RAPID Biomedical, Rimpar, Germany) in phantom images of a standard bottle filled with 5g/l NaCl solution and in head images of a male human in supine (^{1}H/^{23}Na head coil) and prone positioning (^{23}Na dual resonator system), respectively.

RESULTS and DISCUSSION: The B_1-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 B_1-field homogeneity and receive sensitivity is furthermore evident from the first ever acquired whole body ^{23}Na 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 ^{23}Na body resonator in the scanner's housing could enable whole body imaging without the need to repositiong patient between scans. This option could potentially be interesting for ultra high field applications were ^{1}H body resonators cannot be used anymore, which could however be replaced by a ^{23}Na body resonator. Improved whole body ^{23}Na image quality could thus be achieved by the inherently higher polarization at the B_0 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 ^{23}Na resonator with the ^{1}H body resonator of the 3T MRI system. Therefore, the basic frequency and manual shimming was adjusted via the ^{23}Na channel. Compared to the ^{1}H/^{23}Na 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 B_1-homogeneity of developed birdcage coil and achieved high SNR with the single loop surface coil will enable accurate ^{23}Na 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 B_1-field over a large volume while application of organ-specific ^{23}Na receive-only resonators enables to maximize the detectable SNR.

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

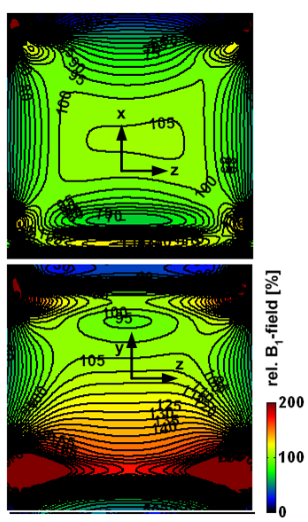

Figure 2: simulated B_1-field maps for asymmetric birdcage coil in xz- (top), and yz-view (bottom).

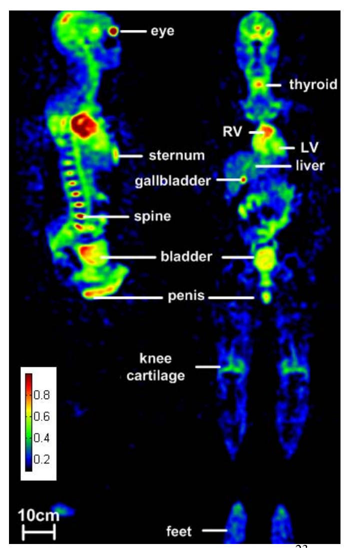

Figure 3: sagittal and coronal ^{23}Na-images [a.u.] of the entire human body.

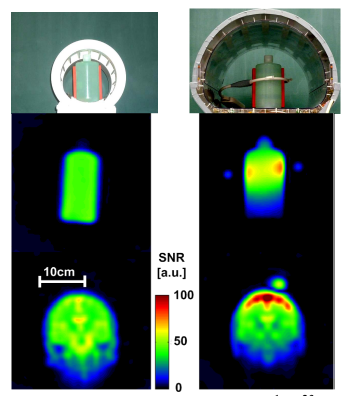

Figure 4: photographs of a) ^{1}H/^{23}Na quadrature birdcage (TXRX,left column) and b) dual resonator system (TORO, right column) and SNR maps of a phantom filled with 100mM NaCl (middle row) and a human head (lower row).

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