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

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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 1H 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 cm horizontal, and 35 cm vertical diameter, 50 cm 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 (0.5 ms) 23Na-MRI, with 6 x 6 x 6 mm³ voxel resolution, TR = 49 ms, 1 ms block pulse, 60° flip angle, 10 min acquisition time, and 60 Hz/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 (27 cm inner diameter, 30 cm length, RAPID Biomedical, Rimpar, Germany) in phantom images of a standard bottle filled with 5 g/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 the inherently higher polarization at the B1 field strength in addition to avoiding co-registration artifacts through moving the patient table after each segment. The reference value for a 180° block pulse of 1 ms length was measured to be 180 V for the head coil and 1200 V for the whole body resonator. Available 300V maximum magnitude provided by X-nuclei power amplifier therefore generated 60° flip angle for 1 ms block pulse – an acceptable trade-off allowing for as low TE as 0.5 ms. 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 100 mM NaCl (middle row) and a human head (lower row).