Sodium Imaging of the Heart at 7T: Design, Evaluation and Application of a Four-Channel Transmit/Receive Surface Coil Array

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Introduction

^{23}Na-MRI is conceptually appealing for gaining a better insight of (patho-) physiological processes and cellular metabolism. Cardiovascular ^{23}Na-MRI has been shown to be suitable for the detection and assessment of acute and chronic heart disease due to increased sodium concentration after myocardial infarction [1-4]. Admittedly, the bi-exponential decay of the ^{23}Na signal and its low sensitivity versus clinical ^{1}H MRI together with long scan times deems ^{23}Na of the heart a challenge. For all these reasons it is conceptually appealing to use the sensitivity gain intrinsic to ultrahigh fields for cardiac ^{23}Na-MRI. These developments are driven by explorations into novel radiofrequency (RF) technology. Realizing this necessity this work proposes a four-channel transmit and receive radiofrequency (RF) coil for 23Na cardiac imaging at 7.0 T. This study includes simulation of electro-magnetic fields (EMF) of the coil design for RF safety evaluation and phantom experiments. Volunteer studies, as a precursor to a broader clinical study are performed and demonstrate the feasibility of clinically relevant ^{23}Na imaging of the heart.

Materials and Methods

The RF-coil consists of an anterior and a posterior section, each containing two 210 x 140 mm² rectangular elements connected with a shared conductor as shown in Fig. a. The four coil loops were constructed on two modestly curved lightweight formers to conform to an average chest and back as illustrated in Fig. b. EMF-simulations were performed using CST Studio Suite 2011 (CST AG, Darmstadt, Germany) together with the voxel model Duke from the Virtual family (ITIS Foundation, Zurich, Switzerland). The coil was tuned to 78.6 MHz which corresponds to the resonance frequency of ^{23}Na at the 7T Magnetom scanner. B1+-fields were calculated for each element and utilized for a B1-shimming routine using optimization algorithms for B1+-field homogeneity (pTX PulseDesign Suite, Siemens, Erlangen, Germany), with a chosen region of interest in the heart. The resulting phase settings were applied in specific absorption rate (SAR) calculations averaged over 10g of tissue (SAR10g). The input power was adjusted according to the SAR10g-estimation of six different phase settings to meet the regulations of the IEC guidelines 60601-2-33 Ed.3.

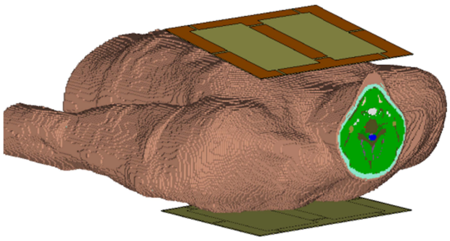
For the assessment of the RF characteristics a 8-channel network analyzer (Rohde & Schwarz, Munich, Germany) was used. In-vivo studies were performed in healthy volunteers using a 7 T whole body MRI system (Magnetom, Siemens, Erlangen, Germany). The volunteers were positioned prone to reduce artifacts due to respiratory motion. Two sets of ^{23}Na MRI experiments were conducted including (i) 23Na localizer imaging was performed with untriggered gradient echo (2D FLASH) imaging (FOV 320x380, TE=2,28 ms, TR=5,6 ms; TA=1,32 min; matrix size 5x5x40 mm³, averages 256, flip angle=20°) and (ii) Short axis images were acquired with a cardiac triggered gradient echo (2D FLASH) sequence (FOV 282x379, TE=2,24 ms, TR=200 ms; TA=11,23 min; matrix size 5,4x5,4x40 mm³, averages 400, flip angle=40°) of the heart. For triggering an acoustic cardiac gating device (easyACT, MRI.Tools GmbH, Germany) was used [5].

Results

The reflection coefficient of each element was measured to be better than -18 dB. Transmission coefficients between adjacent elements were less than -16 dB. Transmission coefficients between the anterior and posterior elements were less than -23 dB. The average Q-ratio of the unloaded- to loaded-coil was 8,4.

For any tested phase configuration, the corresponding partial body SAR, including radiation losses, did not exceed 0,52 W/kg using an input power of 10 W and 1,04 W/kg using an input power of 20 W. This is well within the limits of whole body SAR provided by the IEC 60601-2-33 (6,57 W7Kg in normal mode). SAR10g hotspots were distributed along the conductors with a maximum SAR10g along the centre conductor. It was found that, the simulation resulted in a maximum local SAR10g of 19 W/kg with an input power of 20 W for the tested phase settings and thus did not exceed the 20 W/kg, which is in compliance with the IEC 60601-2-33 Ed.3. The whole body SAR did not exceed a value of 0,282 W/kg.

In vivo studies yielded a rather uniform signal intensity across the heart leading to adequate image quality. An intense signal caused by the high ^{23}Na-concentration of the ribs was observed. A SNR of 27 in the blood pool and 19,6 in the septum led to a blood myocardium contrast of 14 for the untriggered acquisitions. The cardiac triggered acquisitions showed a SNR of 38 in the blood-pool and 24 in the septum and so a blood/myocardium contrast of 3,3 [6].



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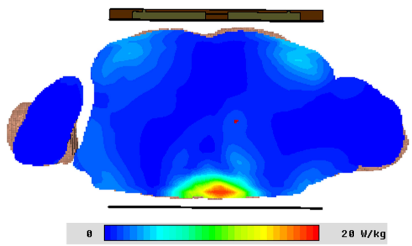

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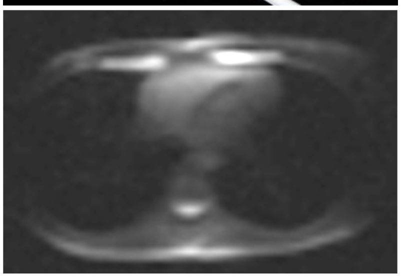

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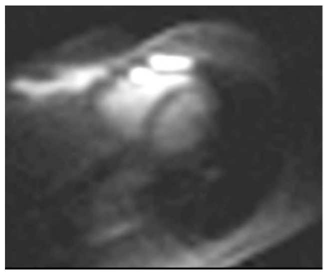

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Figure: a) Voxelmodel in CST Studio Suite with anterior and posterior section of the transceiver coil; b) Photo of the coil; c) SAR distribution with final phase setting using 20 W input power scaled to 20 W/kg in a transversal slice positioned in the middle of the coil; d) Axial ^{23}Na localizer acquired with untriggered 2D FLASH imaging e) ^{23}Na short axis view of the heart acquired with an optimized triggered 2D FLASH sequence.

Conclusion

Our results demonstrate that ^{23}Na-MRI of the heart is feasible at 7.0 T. The proposed RF coil design yielded adequate image quality within clinically acceptable scan times for free breathing, cardiac triggered acquisitions. The presented RF coil shows good RF characteristics as well as B1+ homogeneity. Using an even larger number of TX/RX channels would help to further boost SNR and spatial resolution together with scan time shortening. We anticipate to incorporate the proposed coil design in a ^{1}H/^{23}Na double tuned architecture to combine anatomical and functional imaging (^{1}H) with metabolic imaging (^{23}Na).

References

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