High Resolution Double Resonant ^{1}H/^{19}F RF Coil for Small Rodent MRI and MRS at 3T

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Target Audience: Basic MR researchers, imaging scientists, clinical scientists, radiologists, cardiologists, RF coil engineers, highfield experts, applications specialists

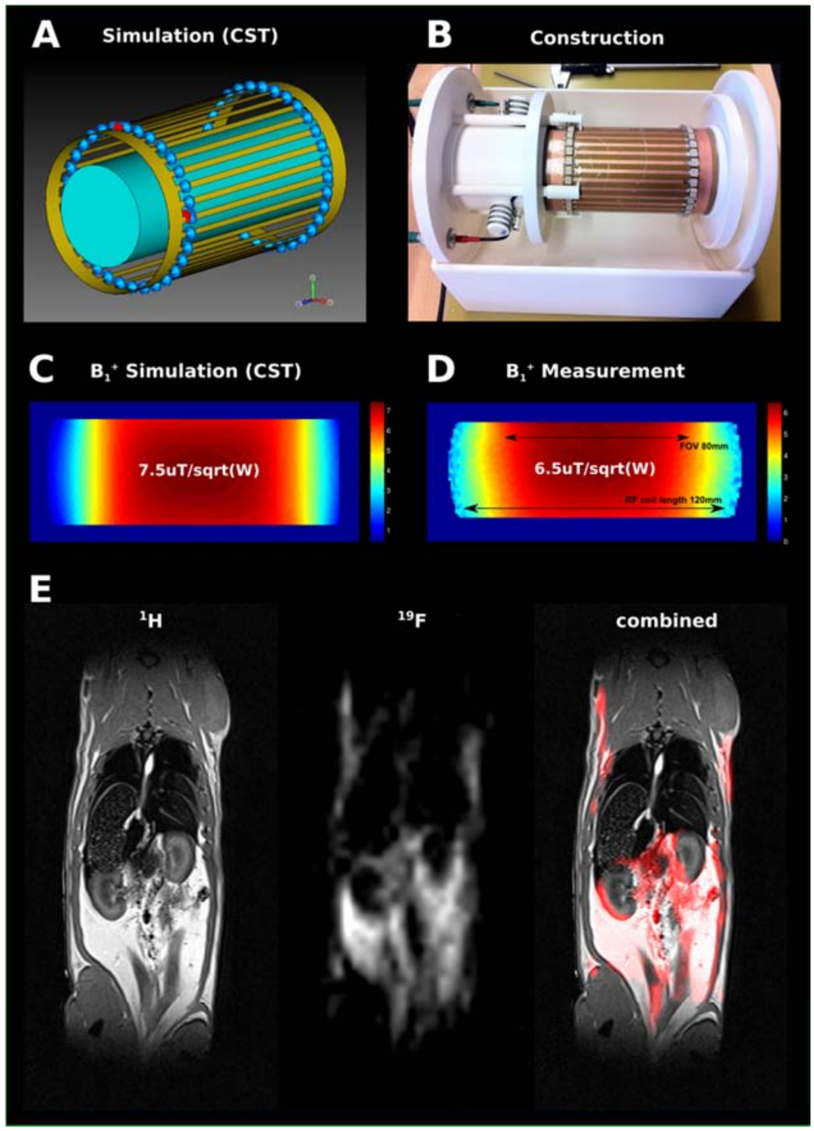
Purpose: Due to the low abundance of ^{19}F in mamals, there is no background signal for ^{19}F MR imaging and spectroscopy. Therefore ^{19}F MR is conceptually appealing to pursue spatio-temporal tracking of implanted cells or cell groups with ^{19}F labeling [1]. This requires dedicated RF coils that provide B_1^+ homogeneity and high sensitivity for very low concentration of ^{19}F labeled cells and that facilitate high spatial resolution anatomical ^{1}H images together with appropriate decoupling between the ^{1}H/ ^{19}F signal channels. Realizing these challenges and the opportunities of ^{19}F MR this study proposes a RF coil tailored for small rodent ^{19}F/^{1}H MR using a clinical 3.0 Tesla MR system to provide means for translational research. To meet this goal, a coil design customized for rat abdomen is proposed and examined in electromagnetic field (EMF) simulations. A dedicated phantom was constructed to validate the results of the EMF simulations with experimental B_1^+ maps. The applicability of the coil for rat imaging is demonstrated.

Methods: In electromagnetic field (EMF) simulations (CST Microwave Studio, CST AG, Darmstadt) a 32-legged low-pass birdcage [2] and a phantom with relative permitivity $\varepsilon = 78$ and conductivity $\sigma = 0.5$S/m were simulated (Fig A). The geometry of the birdcage was itteratively optimized to reach the required anatomical coverage as well as capacitor values that are commercially available. Co-circuit simulation using Advanced Designs Systems (ADS, Agilent) was employed to tune and match the birdcage. The following design was derived from the EMF simulations: diameter=78mm, leg length=110mm, leg width=3mm, end-ring (ER) width=5mm. The same dimensions were used to etch the birdcage layout on a 0.2 mm thick substrate. Ceramic capacitors (ATC, MD, USA) with values deduced from the co-simulation were soldered to the layout. For matching and tuning variable capacitors (Voltronics, MD, USA) were used. Cable traps were added to each channel. A rigid coil casing, a coil holder, tuning and matching tools as well as the animal handling bed were manufactured by rapid prototyping (BST1200es, Stratasys, USA) (Fig B).

To validate the simulation B_1^+-measurements were performed at 3T (Verio, Siemens Healthcare, Erlangen, Germany) using a Bloch-Siegert B_1-mapping technique [3] (Fig. D) with a constructed phantom which uses material parameters identical to those employed in the simulations. Ex vivo MRI of the abdomen of a rat (320g) was performed using ^{1}H-MRI: 2D RARE, TR/TE=13000/72ms, resolution=(0.4x0.4x1) mm^3, TA=7:40min; ^{19}F-MRI: 2D-FLASH, TR/TE=200/1.7ms, FA=20°, resolution=(2.5x2.5x5)mm^3, avg=256, TA=27:20min (Fig. E). The measured ^{19}F signal is due to the residual isoflurane used for terminal narcosis of this rat, which is primarily absorbed in fatty tissue.

Results: The RF coil characteristics support rats with a weight ranging from 280g-400g. The B_1^+ field maps derived from the EMF simulations provided B_1^+ efficiency of 7.5 µT/sqrt(W) in the center of the phantom (Fig C). In comparison, the measured B_1^+ using the constructed phantom provided a B_1^+ efficiency of 6.5 µT/sqrt(W) (Fig D). The S-paramters S11/S22 were found to be ~ -30dB while decoupling was smaller than -20dB. The B_1^+ profiles showed a fairly good agreement between the simulations and the measurements (Fig C and D). Ex vivo ^{1}H/^{19}F data obtained from a rat at 3.0 T are shown Figure E.

Discussion: A dual-tuned ^{1}H/^{19}F birdcage coil with high B_1^+ homogeneity has been constructed. Very good agreement between the simulated B_1^+ fields and the measured B_1^+ maps was demonstrated including anatomical coverage, B_1^+ distribution and B_1^+ efficiency in µT/sqrt(W). The minor difference of 1 µT/sqrt(W) can be attributed to the measured Q_{loaded} values which were 16% lower versus the simulations ($Q_{l(EMF)}$=49, $Q_{l(measured)}$=41). The acquired ex vivo images showed superb sensitivity for ^{19}F MRI and demonstrated high spatial resolution for ^{1}H MRI.



Conclusion: To summarize, our work demonstrates the feasibility of a double tuned birdcage coil tailored for ^{1}H/^{19}F MR in small rodents using a clinical 3T MR system. The proposed RF coil provided high homogeneity and sensitivity even for very low concentrations of ^{19}F. This progress may serve to enhance the capabilities of ^{19}F MR based cell tracking in small rodents. The benefits of such improvements would be in positive alignment with the needs of translational research en route to ^{19}F MR in large animals or humans.

References:

[1] H. Waiczies, S. Lepore, N. Janitzek, U. Hagen, F. Seifert, B. Ittermann, et al., Perfluorocarbon particle size influences magnetic resonance signal and immunological properties of dendritic cells., PLoS One. 6 (2011)

[2] H. Waiczies, S. Lepore, S. Drechsler, F. Qadri, B. Purfürst, K. Sydow, et al., Visualizing Brain Inflammation with a Shingled-Leg Radio-Frequency Head Probe for ^{19}F/^{1}H MRI , Scientific Reports. 3 (2013).

[3] F. Carinci, D. Santoro, F. von Samson-Himmelstjerna, T.D. Lindel, M.A. Dieringer, T. Niendorf, Characterization of phase-based methods used for transmission field uniformity mapping: a magnetic resonance study at 3.0 T and 7.0 T., PloS One. 8 (2013)