RF Coil Local Power Deposition and Efficiency Evaluation Using a Phantom with High Sensitivity to Temperature Change

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Introduction: A common approach for evaluating the efficiency of a conventional transmit coil is to measure the amplitude of the created B1 field or spin flip angle for a given certain input power[1]. This work utilizes temperature and flip angle mapping as a tool to calculate transmit coil efficiency map at each voxel to compare transmit efficiency of coils. In recent works, local temperature mapping has been used as a mean to evaluate local power deposition via proton resonance frequency shift (PRF) of water while using fat as reference for non-temperature related B_0 changes. Using the PRF method to map temperature change have three main limitations[3]: first, the chemical shift of water is small (~0.01 PPM/deg C) therefore water is less sensitive to temperature changes. Second, thermal sensitivity of water may change among different tissues. Third, PRF is easily corrupted by B_0 field changes. In this work, we used paramagnetic thulium 1,4,7,10-tetraazacyclodo- decane–1,4,7,10-tetraacetic acid (TmDOTA-) complexes introduced to a gel phantom to provide a means for more accurate and sensitive temperature mapping that is less sensitive to B_0 changes. The chemical shifts of the proton signal from TmDOTA- are hundreds of PPM away from water allowing the selective excitation of the compound of interest [2,3]. The use of TmDOTA- in a phantom enabled absolute temperature measurement that is >100 times more sensitive to temperature change than water [2]. This enables measuring smaller RF exposures compared to previous studies that use traditional PRF as a mean to map temperature changes. Preliminary results are presented where temperature was mapped based on TmDOTA-'s frequency shift and combined with the information provided by B1 mapping sequences enabled local calculation of the RF coil efficiency map.

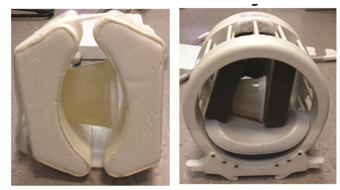

Figure 1. Coils used for efficiency comparison. Left- carotid coil. Right-birdcage coil.

Methods and Results: A cylindrical phantom with a height of 8cm and a diameter of 12cm was created by using the following ingredients: water=500ml, sugar=150g, NaCl=10g, benzoic acid=0.5g, 4% (w/v) agar, and 6mM TmDOTA-. The resulting mixture was heated to approximately 80 degrees Celsius and was allowed to cool to room temperature to form a stable gel with conductivity and relative permittivity of 2.16 S/m and 62 at 300 MHz (Agilent 85070E Dielectric Probe Kit, Agilent Technologies, Germany), respectively. Three fluoroptic MR-compatible temperature probes (Luxtron) were inserted into the phantom to record the temperature of the phantom throughout the experiment. The fifth hydrogen (H5) of TMDOTA- was imaged since it is favorable in terms of T2, sensitivity to temperature and it's frequency was far from the frequency of water (~250ppm away) such that the RF pulses used did not excite the water. The T1 and T2 of H5 ~1.2ms and ~1.4ms, respectively. For the imaging studies, two spoiled 2D GRE of TmDOTA were acquired- one before RF heating and one after heating. For the imaging of TmDOTA- a single slice low res 2D spoiled GRE with the following parameters was used: TE=0.85 ms, TR=10 ms, transmit flip angle =29 degrees, matrix size = 40x20, voxel size=6x6x10 mm^3, number of averages=1024 and acquisition time = 3:41 minutes. Thereafter an RF heating sequence with 100% SAR was played out for 10 minutes followed by a second identical low res 2D spoiled GRE. After the two GRE and heating pulse finished a flip angle map was acquired [4] using the same reference voltage. The same protocol was run on two different coil structures: 1. A carotid coil (Figure 1, left) with 1 transmit coil and 8 receive coils element. 2. A birdcage coil(Figure 1, right). The acquisitions were then exported into Matlab (MathWorks, Inc., Natick, MA, USA) for post processing. The phase difference between the two 2D GRE images was then used to calculated the temperature change using the following equation: $\Delta T = \frac{\Delta\phi}{\alpha * TE * \omega}$, where α is the chemical shift coefficient of H5=1.31ppm/C [2], TE is the echo time and ω is the center frequency of acquisition. Temperature maps are shown for a transverse slice in Figure. 2. Temperature measurements acquired using the fluoroptic MR-compatible temperature probes shown in Figure 3. An efficiency metric at each voxel within the field of view was calculated using the following equation: $\xi(r) = \frac{FA(r)^2}{\Delta T(r)}$, where FA is the flip angle and ΔT is the temperature at the r-th voxel. Results of the efficiency metric for the two coil configurations are shown in Figure 2 (right column).

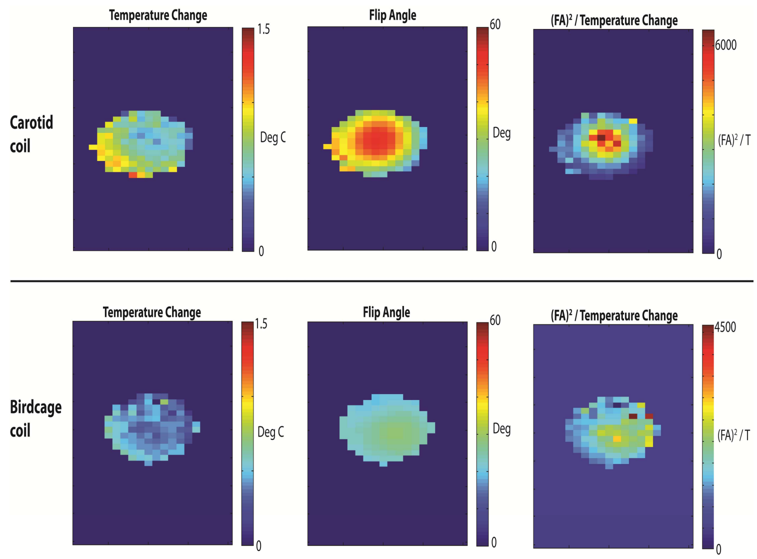

Figure 2. Left- temperature change maps (in degrees centigrade). Middle - flip angle map. Right- efficiency map $(FA)^2/\Delta T$.

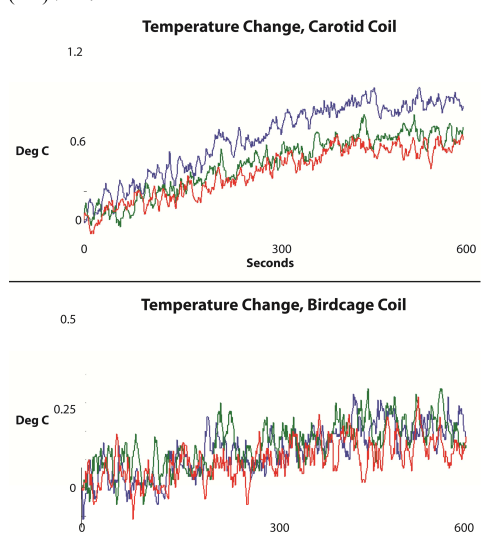

Figure 3. Temperature change when an RF pulse was played out at 100% SAR for 10 minutes. Results show temperature measured using three optical probes positioned at the center of the phantom when a carotid (top) and a birdcage (bottom) coils were used.

Discussion and Conclusion: This work utilizes the high temperature sensitivity of TmDOTA- to measure the temperature change due to a 100% SAR pulse played out for 10 minutes. Combining the high sensitivity to temperature change and the insensitivity to B0 changes, this compound shows preliminary, yet, promising results. One drawback of this phantom is the low concentration of TmDOTA- (6mM), which caused imaging of the compound to be high in SAR and relatively lengthy (3:41 minutes) with the requirement of multiple averages. Increasing compound concentration of the phantom is expected to improve the SNR of the measurement, reduce the time needed to acquire images by reducing the number of averages, reduce the SAR of the sequence and improve accuracy of the temperature mapping. That said, this work shows preliminary results where temperature change was mapped using TmDOTA- and combined with B1 mapping enabled local calculation of the RF coil efficiency metric which can be used to evaluate and compare different transmit coil structures.

References: [1].Zhu, Y. Proceedings ISMRM 2010 page 1518.. [2]. Zuo, C. S., et al. J Magn Reson 151, 101-106, doi:10.1006/jmre.2001.2356 S1090-7807(01)92356-0 [pii] (2001). [3]. Hekmatyar, S. K. et al. the official journal of European Society for Hyperthermic Oncology, Group 21, 561-574, oi:10.1080/02656730500133801 (2005).3 [4]. Yarnykh, V. L. Magn Reson Med 57, 192-200, doi:10.1002/mrm.21120 (2007).