B1+-based SAR assessment using a birdcage coil at 7 Tesla: experimental evaluation using magnetic resonance thermometry

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Target audience: MRI physicists

Introduction: Specific absorption rate management in general heavily relies on numerical simulations performed on a few available human body models. The new emerging field of *Electric Properties Tomography* has shown great promise to provide patient-specific information about the electric field via the post-processing of measured $B1^+$ data utilizing Maxwell's equations. The work of Voigt et al[1] furthermore showed a good correlation between the numerically determined SAR distribution and the one based on the post-processing of the $B1^+$ field at up to 3T. A global offset between the two however was observed. The purpose of this work was to experimentally evaluate this B1-based SAR determination via temperature measurements at 7T with a birdcage coil and with a phantom of known electrical properties.

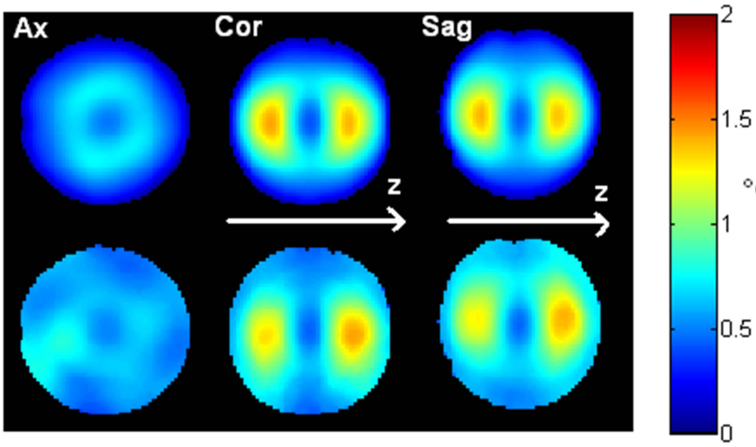
Materials and methods: Experiments were performed on a 1 % agar gel spherical water phantom (15.8 cm diameter) doped with salt (4 g/l), on a 7T standard scanner and using a birdcage coil. Measurements of the electric properties[2] yielded a conductivity σ=0.78 and permittivity ε=74.3. The $B1^+$ and ΔB0 maps were measured by using the modified AFI sequence[3] with the following parameters TR = 150 ms, n = 5, resolution = 3 x 3 x 3 mm^3, matrix = 64 x 64 x 64. Three echoes were inserted in the first TR to monitor and fit the ΔB0 in every voxel. The phase of the $B1^+$ field was calculated from the measured transceive phase φ rewound by this ΔB0 evolution during TE and during the pulse itself[4], and using the approximation[1] $\varphi^+=\varphi/2$. Ignoring the non-measured H_m and H_z components of the magnetic field, the $B1^+$-based SAR was computed with $SAR=\sigma/(2\rho)|\vec{E}|^2$ and with the electric field squared given by[1]:

$$\left|\vec{E}\right|^2 \approx \frac{1}{|\omega\kappa|^2} 2\left[\left|\partial_z H_p\right|^2 + \frac{1}{2}\left|\partial_x H_p\right|^2 + \frac{1}{2}\left|\partial_y H_p\right|^2 + Real(i\partial_x H_p \partial_y H_p^*)\right] \quad (1)$$

with κ=ε-iσ/ω (Larmor frequency ω) and where H_p is the measured RF field co-rotating with the spins and defined in the laboratory frame by[5] $\frac{1}{2}(H_x + iH_y)$. A 5 x 5 x 5 smoothing gradient filter was applied to smooth the data and calculate the derivatives. The above calculation returned the SAR at every point for the voltage used in the AFI sequence. The Proton Resonance Frequency (PRF) method in magnetic resonance thermometry was used to measure the temperature rise[5]. A GRE sequence (matrix = 32 x 32 x 32, TR = 33 ms, TE = 25 ms) first was carried out to acquire a reference phase with negligible energy deposit. Then a 3 ms square pulse (V = 400 Volts, duty cycle = 2 %) was applied for 10 minutes, which constituted an RF heat source 20 times larger than the one arising from the AFI sequence. No gradients were applied during this heating period. The same GRE sequence was then implemented to measure the new phase image. The temperature increase was then calculated using[6] $\Delta T=\Delta\varphi/(\alpha\omega TE)$, with ω being the Larmor frequency at 7T (~297 MHz). The α coefficient was determined by fitting a linear function of the measured phase versus the temperature recorded by an optical probe at one location. Ten independent and consecutive 3D GRE sequences adding up to 20 minutes were carried out in order to assess phase stability just prior to the heating sequence. The SAR distribution obtained from Eq. (1) was used as an input to simulate the temperature rise by integrating the heat diffusion equation. A global scaling factor was applied to the calculated SAR distribution and was varied in order to minimize the root mean square error (RMSE) between the obtained temperature distribution and the thermal measurement.

Results: The α coefficient was measured to be -0.013 ppm/°C (correlation of the linear fit of 0.9992). Over 20 minutes, the preheating phase stability experiment revealed a small linear frequency drift of 0.002 ppm/hour, for which corrections were made. Minimum RMSE between the computed thermal rise and the experimental one was obtained for a scaling factor of 1.87 (correlation of 0.76, RMSE = 0.07 °C). The spatial correspondence between the maps is good, but with the peak temperature of the $B1^+$-based estimation slightly larger than the measured value (1.6 °C versus 1.4 °C). Not integrating the heat diffusion equation yielded a worse correlation of 0.53. A scaling factor of 1.65 equalizes the two peak temperatures but raises the RMSE to 0.08 °C. The temperature distributions are provided in the figure below. The asymmetry in the two lobes in the thermal measurement along the z direction (coronal and sagittal slices) can be due to the fact that the phantom was likely not perfectly centered, a trend confirmed by HFSS (Ansys, Canonsburg, PA, USA) simulations.

Conclusion: At 7T and using a birdcage coil, results show a fairly good correspondence between the $B1^+$-based prediction and the measured temperature increase, provided the result in Eq. (1) is multiplied by a factor of 1.87. This calibration factor can be used to directly assess the SAR in real conditions using measured $B1^+$ maps.



Refs: 1. T. Voigt et al. MRM 68:1117-1126 (2011) 2. A. Nicolson and G. Ross. IEEE Trans. Inst and Meas 19:377-382 (1970). 3. A. Amadon and N. Boulant. ISMRM Toronto, Canada, p 1248 (2008). 4. N. Boulant et al. ISMRM Stockholm, Sweden, p 4918 (2010). 5. D. I. Hoult. Concepts of Magn Res 12:173-187 (2000). 6. V. Rieke. JMRI 27:376-390 (2008).

Figure: Axial, coronal and sagittal (from left to right) slices of the temperature rise for simulations based on $B1^+$-based SAR data scaled up by 1.65 (top) and measurements (bottom).

Acknowledgments: The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Program (FP7/2013-2018) / ERC Grant Agreement n°309674.