# An anatomically realistic temperature phantom of the head for validation of SAR calculations

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**Introduction**: Parallel Tx can improve imaging performance at high fields,[1], but complicate the prediction and validation of local SAR values[2]. Such local SAR "hotspots" can cause harmful local increase of temperature. SAR induced temperature increases can be computed using electromagnetic and temperature simulations, however these are complex calculations and require validation. For this purpose we constructed a temperature measurement phantom, which consists of multiple tissue compartments that match those of the human head both in terms of their geometry and their electrical properties. The phantom contains a temperature sensitive contrast agent (TmDOTMA) allowing 3D temperature imaging with an accuracy of 0.1-0.2 °C [3].

**Methods**: *Phantom:* Since electromagnetic fields superposition from the array elements depend strongly on the shape of the propagation medium (Fig. 4), we based our phantom on a high-resolution 3D MR scan of a single human subject [4]. The MR data was segmented manually into four compartments: i) brain (WM, GM and CSF), ii) muscle, iii) eyes and iv) low conductivity compartments modeling air, bone and fat. This last compartment implemented PC-ABS plastic using a 3D printing service (RedEye on Demand,USA) and also served as the outer shell of the phantom. Several small holes in the phantom allow the insertion of fiber optic probes (Lumasense Technologies) for direct temperature measurement validation. The other compartments were filled with gels with relative permittivity ($\varepsilon_r$) and conductivity ($\sigma$) matching those of the brain ($\varepsilon_r$=50.8±0.7 $\sigma$=0.63±0.01S/m), muscle ($\varepsilon_r$=58.7±0.9 $\sigma$= 0.72±0.01S/m) and eyes ($\varepsilon_r$=68.6±0.7 $\sigma$=1.65±0.03 S/m) by adding different concentrations of polyethylene powder and salt to the agar gel.[5] We measured the electrical properties of the gels using a dielectric probe (Agilent Technologies).

All gels were doped with 2mM of TmDOTMA (which has a temperature dependent chemical shift of 0.6ppm/°C) synthesized from DOTMA (Macrocyclics) and thulium chloride. *Temperature mapping*: MR image phase ($\Delta\phi$) and temperature ($\Delta T$) are related via $\Delta T = \Delta\phi / (2\pi\gamma B_0 \times c \times TE)$ [6], where $c$ is a temperature coefficient in ppm/°C. To estimate $c$ for TmDOTMA, we performed a cooling experiment using a small sample of TmDOTMA in a 30mm solenoid coil. Since TmDOTMA has a chemical shift of -110 ppm we excited it by playing a 2.56 ms sinc RF pulse -31.5 kHz off resonance by manually shifting the scanner center frequency. RF heating was applied and 3D GRE phase images were acquired for 60min using the parameter values TE=3ms, TR=10ms, 64x64x24 matrix, voxel size=2mm isotropic, BW=1184Hz/pixel and flip angle=85°. Temperature was also measured continuously using a fiber optic probe allowing fitting the phase difference data for $c$. As a validation, we performed the same experiment with a different amount of RF heating and compared the fiber optic to the MR temperature measurements.

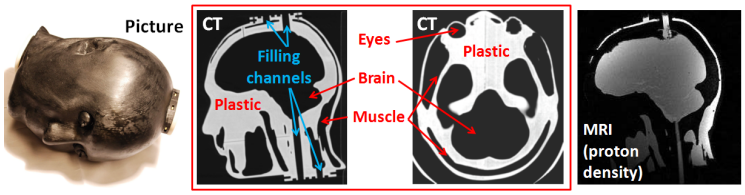


*Fig. 1. Fotograph, CT and MRI scans of our realistic head phantom.*

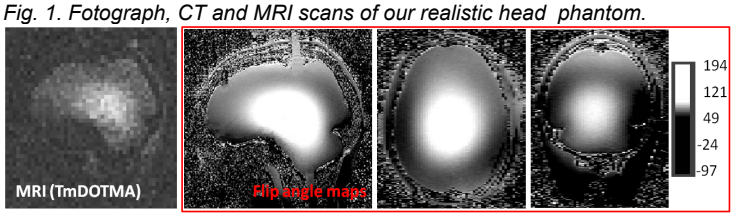


*Fig. 2. MR Image on TmDOTMA resonance frequency and flip angle maps.*

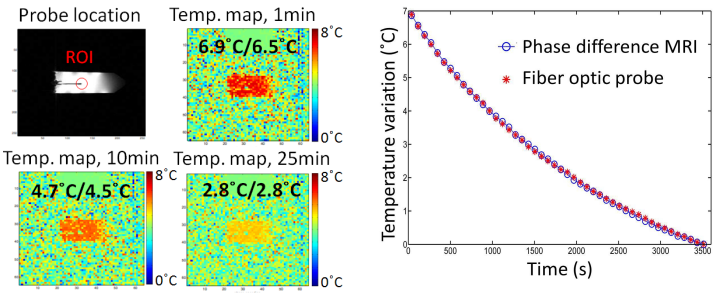


*Fig. 3.Calibration of Temperature Imaging using TmDOTMA on a small sample **Left**: Temperature maps acquired at 1, 10 and 25min. after RF heating (validation step). Shown on these maps are temperatures variations measured using the fiber optic probe (first number) and averaged in an ROI on the MR temperature maps (second number). **Right**: 60min. cooling curve (validation step).*

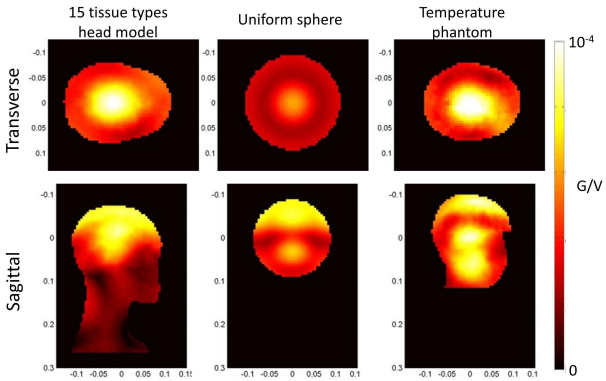


Fig. 4. Electromagnetic simulations of |B1+| maps for a 15 tissue types head mode, a uniform sphere of brain tissue and our temperature head model.

**Results**: B1+ profiles of our temperature phantom showed the typical central brightening pattern observed in humans at 7T (Fig. 2). Moreover, electromagnetic simulation of a "full" head model (Ansys), a uniform sphere of brain tissue and our temperature phantom confirmed that accurate modeling of the principal electrical head compartments is important for reproduction of the electromagnetic fields observed in vivo (Fig. 4). The temperature calibration experiment/fit yielded a value of $c$ =0.62 ppm/°C, which agrees with published values [3]. Using this value in the subsequent validation experiment yielded MR temperature estimates in good agreement with the fiber optic probe measurements (error<6%, see Fig. 3).

**Conclusion**: We have built an anatomically and electrically realistic temperature head phantom that will be crucial for validation of electromagnetic and temperature simulations of the human head in parallel transmit head arrays.

**References**: [1] Setsompop, K. (2008). MRM **60**(6): 1422-1432.; [2] Wu, X. (2010). Jour. Mag. Res. **205**(1): 161-170.; [3] James, J. R. (2009). MRM **62**(2): 550-556; [4] Angelone et al. (2005). ISMRM; [5] Ito, K. (2001). Elec. Comm. Jap. **84**(4): 1123-1135; [6] Shapiro, E. M. (2002). MRM **47**(3): 492-498.