EM and thermal validation of a numerical elliptical birdcage at 3T

Mélina Bouldi[1] and Jan M. Warnking[1,2]
[1]Grenoble Institut des Neurosciences - UJF, Grenoble, Rhône-Alpes, France, [2]Inserm U836, Grenoble, Rhône-Alpes, France

Target audience: Physicists, Engineers

Purpose:
Understanding the risks of overheating due to the presence of active implants requires a rigorous simulation of experimental conditions. As a first step towards such simulations, we sought to build and validate a model of the whole body transmit coil in a Philips Achieva TX® system. According to [1], tuning a birdcage consists in finding the continuous current distribution, which allows creating a circularly polarized magnetic field**.** The model was tuned to set the resonance at the Larmor frequency of protons at 3T. To validate the model, we first compared simulated and theoretical current distribution on legs. Then, we compared the radiofrequency field distribution coming from experiment and simulation. Lastly, we compared simulated and measured local variations of temperature during RF heating.

Material and methods:
Experimental set-up: A phantom, previously built respecting to ASTM F2182-09 [2], was filled with a medium consisting of sodium chloride (1g/L) and hydroxyethyl-cellulose (25g/L) in water, with a low frequency conductivity of 0,434S/m (Conductimeter Mettler Toledo®). Three fiber-optic temperature sensors (Photon Control®) were placed in the gel, near the lateral borders of the container. The phantom was centered in a 3T TX Achieva MR scanner (Philips Healthcare®). The system body coil was used for RF transmission. The transmitted radiofrequency field B_1 was obtained by an actual flip angle imaging (AFI) pulse sequence, using [3], with TR_1 = 30ms and TR_2 = 150ms. A multi-slice multi-echo sequence was acquired for maximal heating (B_1^{RMS} of 2,29µT). The precise timing and B_1^{RMS} of all sequences was recorded to replicate the experiment in the thermal simulation.
Electromagnetic and thermal simulations: Simulations were performed using commercial FDTD software (SEMCAD®, version 14.8, SPEAG, Zürich). We aimed to implement a numerical model of the whole body RF transmit resonator resembling the actual resonator as closely as possible. The actual resonator in our system is slightly elliptical, so the structure chosen for the RF coil was an elliptical 16-leg birdcage coil, with an aspect ratio of 3:2.75, shielded, band-pass. The excitation was sinusoidal (16 sources, situated in the middle of each leg, with successive current phases shifted by $2\pi/16$). We adjusted the capacitances in legs and end-rings to tune the birdcage to 128 MHz. The birdcage was loaded with a thermally insulated phantom model. Three thermal sensors were placed at the same position as in the experimental set-up (Figure 3), and we simulated the temperature increase distribution according to the Pennes' heating equations.
Data processing: Both real and imaginary part of the current density distribution as a function of the leg number is obtained (Figure 1). The root mean square of the B_1^+ field vector of the phantom was extracted from the EM simulation. The MRI and simulated data were interpolated to the same grid. Simulated data was masked to the region available in the MR measurement to facilitate comparison (Figure 2).

Results & Discussion:

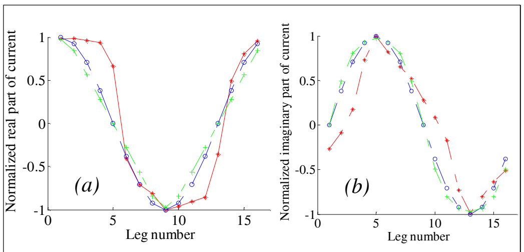

Figure 1

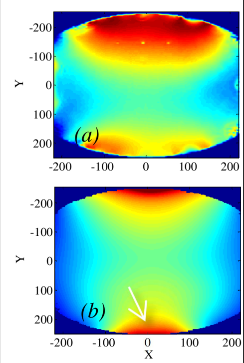

Figure 2

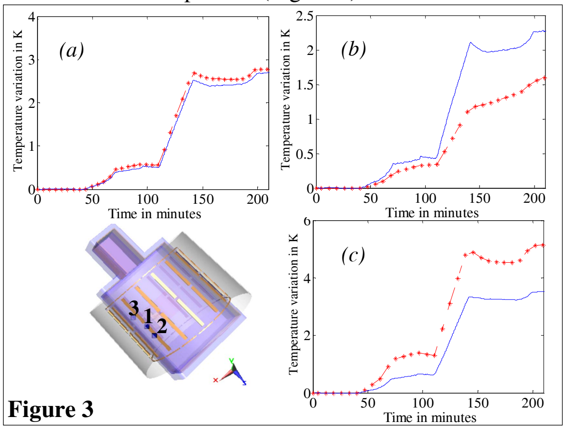

Figure 3

Figure 1: In blue the pure sine/cosine current distribution of a standard circular birdcage; in green, the theoretical current for an elliptical birdcage with 3:2.75 aspect ratio [1]; in red, the observed distribution from the simulation**. Figure 2:** Experimental *(a) vs* simulated *(b)* B_1 map. **Figure 3:** Simulated phantom with sensor positions (blue squares). Temperature variations: experiment (blue) *vs* simulation (red). *(a)* Sensor 1, *(b)* sensor 2 and *(c)* sensor 3.

The observed current distribution in the legs still presents an asymmetry even though the birdcage is correctly tuned to the simulated RF frequency (Figure 1). This may be one of the origins of the differences obtained between the simulated and experimental B_1 maps (white arrow in Fig.2). Heating periods are well reproduced in the simulation for sensor 1 (Fig. 3a), but the concordance is only qualitative for sensors 2 and 3 (Fig. 3b-c). The continued temperature increase in the simulation for sensor 2 after the end of the heating period (at 142 minutes) indicates the presence of nearby hot spots. This sensor is placed close to the upper surface of the phantom gel. The difference in sensor 3 (located close to the bottom of the gel) seems to be mainly due to a difference in local SAR between simulation and experiment. These results show us that the simulation of SAR and temperature near the phantom surfaces, where these quantities show strongest spatial variation, leaves room for improvement.
Due to severe image distortions in our phantom experiment at the border of the FOV (width of the container: 51cm), acquired temperature maps did not permit comparison with simulated maps. New experiments are going to be done with a smaller phantom. Comparing simulated and acquired temperature images will allow detecting discrepancies or hot spots hinted at by our local temperature measurement.

Conclusion:
Our method of validation, using comparison between theoretical and measured current distribution, and comparison between simulated and experimental B_1 and temperature maps, permits to assess the validity of the resonator model, and paves the way to a realistic numerical elliptical resonator model.

References and acknowledgment:
[1] Leifer et al., MRM 38:726-732 (1997). [2] ASTM, F2182-09. [3] Yarnykh et al., MRM 57:192-200 (2007).
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