EM and thermal validation of a numerical elliptical birdcage at 3T in the presence of a long conductive wire

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Target audiences MR engineers and physicists.

Purpose

Understanding the risk of overheating in the presence of implants requires a rigorous simulation of experimental conditions. We built a model of the whole body transmit coil in the Philips Achieva TX® system. The validity of that model was verified by comparing simulations to phantom experiments both for an ASTM phantom alone and the phantom in presence of a long copper wire. Comparisons were performed based on simulated and measured local temperature increase, and RF field maps.

Materials and methods

Experimental set-up: A phantom, built according to ASTM F2182-09[1], was filled with a medium consisting of sodium chloride (1g/L) and hydroxyethyl-cellulose (25g/L) in water, with a low frequency conductivity of 0.388S/m (Conductimeter Mettler Toledo®). A 20 cm long copper wire of 3 mm diameter, insulated with a thin film of varnish along its length and bare at the tips, was placed at 5.5 cm of the left border of the container, aligned with the static field direction. Three fiber-optic temperature sensors (Photon Control®) were placed in the gel, two at each tip of the copper wire, and one at the opposite side of the container, for control. The phantom was centered in a 3T TX Achieva MR scanner (Philips Healthcare®). The system body coil was used for RF transmission. The transmitted radio-frequency field B_1 was measured by an actual flip angle imaging (AFI) pulse sequence [2], with TR_1=30 ms and TR_2=150 ms. We ran several sequences of varying SAR for heating (peak B_1^{RMS} of 2.27 µT). 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 capacities in legs and end-rings to tune the birdcage to 128 MHz. The birdcage was loaded with a thermally insulated phantom model and a wire model. Three thermal sensors were placed at the same position as in the experimental set-up, and we simulated the temperature increase distribution according to the Pennes' bioheat equations.

Data processing: 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 were masked to the region available in the MR measurement to facilitate comparison (Figure 1).

Results and discussions

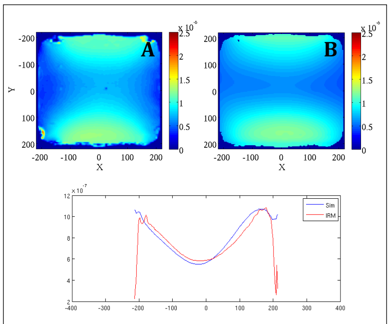

Fig. 1

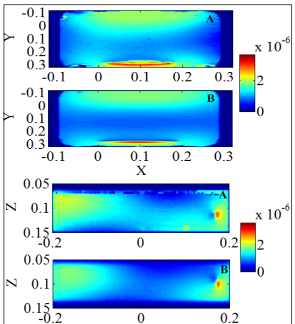

Fig. 2

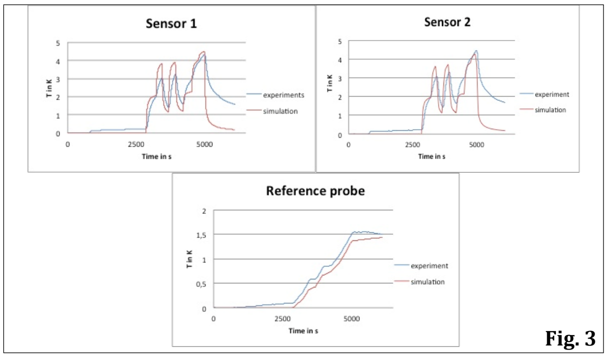

Fig. 3

Fig. 1: *(A) Simulated vs (B) experimental RF field map without the wire. Below, the RF field mean projection along the y-axis (experiment in red, simulation in blue).*

Fig. 2: *(A) Simulated vs (B) experimental RF field map with the wire, from a transversal and a sagittal view.*

Fig. 3: *Temperature variations : experiments (blue) vs simulation (red).*

Simulated (A) and experimental (B) B_1 maps with (Fig.2) or without (Fig.1) wire show good agreements. A difference is observed around the wire electrode in the coronal slice (Fig. 2 - bottom), likely due to a difference in the relative phase between the background B_1 field and the wire current. Heating periods are well reproduced in the simulation for all thermal sensors (Fig. 3). Slightly stronger and faster heating is observed in the simulations, likely due to minute differences in thermal sensor position. Sensors 1 and 2 show identical variation profiles, showing the expected symmetry between wire tips in experiment and simulations.

Conclusion and perspectives

Our method of validation, comparing simulated and experimental B_1 and temperature maps, permits to assess the validity of the EM simulations, and paves the way to a realistic numerical elliptical resonator model. Realistic temperature simulations, as opposed to SAR simulations, provide a metric directly comparable to experimental results and thus facilitate validation.

References and acknowledgments

[1] ASTM, F2182-09. [2] Yarnykh et al., MRM 57:192-200 (2007). This work is supported by a grant from the Rhône-Alpes Region.