Numerical evaluation of small animal warming potential when using a birdcage coil for 7T magnetic resonance imaging

Maíra M. Garcia (1,2), Tiago R. Oliveira (3), Daniel Papoti (3), Khallil Chaim (4), Daniel Erni (2), and Waldemar Zylka (1)

(1) Faculty of Electrical Engineering and Applied Natural Sciences, Westphalian University, D-45897, Gelsenkirchen, Germany

(2) General and Theoretical Electrical Engineering (ATE), Faculty of Engineering, University of Duisburg-Essen, and CENIDE – Center of Nanointegration Duisburg-Essen, D-47057 Duisburg, Germany

(3) Department of Biomedical Engineering, Federal University of ABC, 09606-070 São Bernardo do Campo, Brazil

(4) Department and Institute of Radiology, University of São Paulo, 05403-010 São Paulo, Brazil

E-Mail: maira.martins-garcia@stud.uni-due.de

Abstract – During magnetic resonance imaging (MRI) procedures the patients are subjected to electromagnetic (EM) waves in a radiofrequency (RF) range. The incident waves can be partially absorbed into the patient's body, due to the electromagnetic response of the patient's tissues. The excessive energy absorbed may result in tissue heating which rises concerns about patient safety [1]. The attention increases for MR applications in ultra-high fields (B_0 ≥7T), since the electrical ($\vec{E}$) and magnetic ($\vec{B}_1$) fields components demonstrate more special non-uniformity in these conditions [2]. To investigate the incident EM field distribution and its potential of tissue heating, we designed a transmit/receive linearly driven birdcage coil for small animals and performed a 3D numerical analysis to assess the temperature distribution in a phantom during MRI procedures at ultra-high field (7T). The simulated results suggest that the designed coil can be safely used to investigate small animal heads, since they will not be subjected to an excessive increase in local temperature.

Methodology: To perform the 3D numerical analysis, the commercially available software COMSOL Multiphysics 5.4 (COMSOL Inc., Sweden) was used. The designed high-pass birdcage coil for B_0=7T is made of copper, has a cylindrical shape (diameter: 10cm; height: 16.4cm), has 15 capacitors of 4.3pF and one variable capacitor (5 to 15pF) that are located at its end-rings [cf. Fig. 1a)], and its excitation is done through a single port. An EM shielding apparatus is connected to the coil in order to avoid EM interference from other hardware components of the MRI scanner. The shield has 210cm of height and 150cm diameter. A real coil was additionally constructed and some input information for the simulations was assigned using the values obtained after primary tests at the 7T MRI scanner (Siemens Healthcare, Germany) installed at PISA – imaging platform in the autopsy room, at the University of São Paulo, Brazil.
A MRI procedure was simulated using the voltage of V_0=68.7V for the coil's excitation value and assuming a gradient echo pulse sequence operating during 20 minutes. A spherical phantom with a complex geometry, positioned in the center of the coil, was created in order to represent the head of an animal subject submitted to a MRI procedure. Its geometry consists of a sphere with 7cm diameter, and in its interior part an elliptical shaped region is placed, which consists of a thin layer of bone (1mm) and brain-like tissue; the external region of the ellipse represents a muscle-like tissue [cf. Fig. 1b)] [3]. The initial temperature considered for the phantom was 37°C and the room temperature was 20°C. Finally, to analyze the potential of tissue heating, the software performed a co-simulation, due to its multiphysics capability, where the EM results served as input to calculate temperature maps [4].

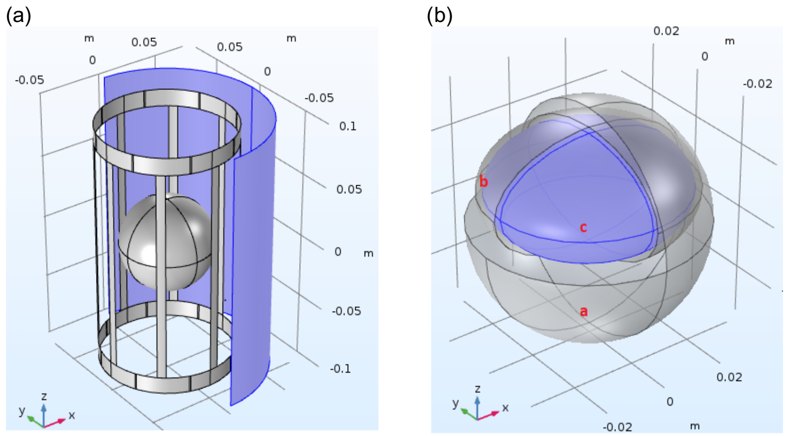

*Fig.1: (a) Birdcage coil geometry, EM shield and the phantom placed in the center of the coil. (b) Phantom geometry. The blue tissue (region **c**) is the brain tissue, region **b** is bone tissue equivalent and region **a** is filled with muscle.*

Results: The predictions of temperature increase after 20 minutes for the object are shown in Fig. 2, where only the axial and sagittal planes are presented.

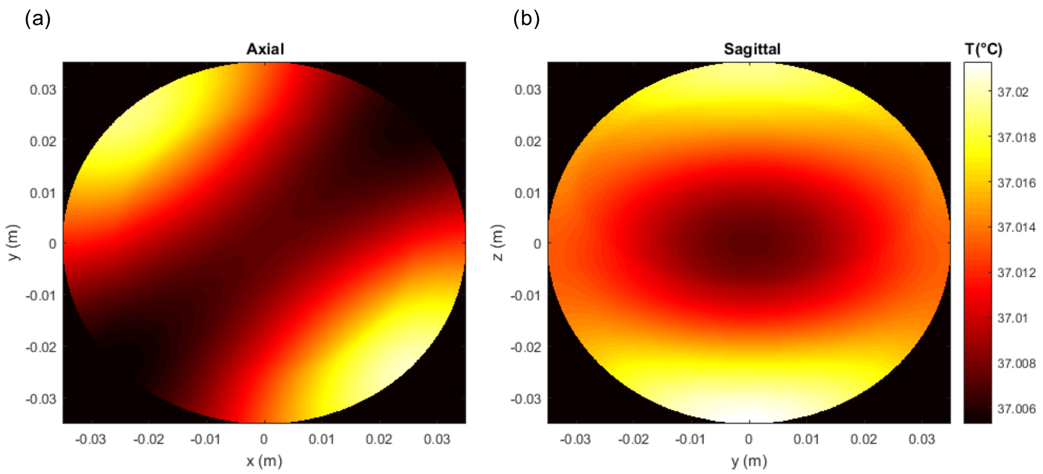

Fig.2: Temperature distribution inside the phantom. In (a) is presented the axial plane and in (b) the sagittal plane.

Discussion and Conclusion: The maximum local temperature limits on a tissue to avoid any unexpected burn are established in literature as 40°C [5]. From Fig. 2 it is possible to observe that the phantom did not suffer significant temperature increase, reaching a maximum local value of 37.02°C, which is far from the safety limit. Therefore, these results indicate that the head of a small animal would not suffer any increase in temperature above the limits, when experiencing a MRI procedure using the designed coil.

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