RF Heating on a Vagus Nerve Stimulation Device during Head Imaging in a 3T Transmit Body Coil using a Numerical Analysis

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Target audiences MR Engineers and Physicists, Physicians interested in MR safety.

Introduction Vagus Nerve Stimulation (VNS) is a treatment recently approved for refractory epilepsy and depression, and under clinical evaluation for others pathologies, like Alzheimer's disease, obesity, headaches and chronic pain [1]. The VNS device consists of a pulse generator (IPG) implanted under the clavicle of the patient, connected using an isolated extension lead to the stimulation electrode that is wrapped around the vagus nerve in the neck region. In order to allow implanted patients to continue to benefit from MRI exams, it is important to assess the MR safety of the implantable devices [2]. The aim of the work presented here was to evaluate the MR safety of the VNS device during head imaging based on phantom experiments. The sensitivity of the experimental results on the precise configuration was qualitatively assessed based on the distribution of electric fields obtained using numeric electromagnetic (EM) simulations.

Materials and Methods: *Electromagnetic simulations:* EM simulations were performed using commercial software (SEMCAD®, version 14.8, SPEAG, Zürich). We implemented a numerical model of the whole body RF transmit resonator tuned at 128 MHz resembling the actual resonator as closely as possible. Harmonic EM simulation centered at 128 MHz provided the electrical field maps E_{map} for numerical models of the phantom as well as of a human body model (Hugo) from The Virtual Family toolbox [3], in the absence of a VNS device.

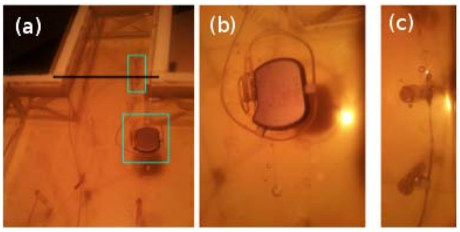

Fig. 1 : (a) Global view of the experimental setup; (b) Zoom on the IPG; (c) Zoom on the contacts

Experimental set-up: A phantom built according to [4] was filled with 32 L of gel consisting of sodium chloride (1 g/L) and hydroxyethyl-cellulose (25 g/L) in water, with a low-frequency conductivity of 0.42 S/m (Conductimeter Mettler Toledo®) (*Fig. 1a*). A Cyberonics VNS device (Model 101 NCP) was examined. The two contacts (distal and proximal) were fixed at 2 cm of the left border of the "head" of the phantom, at 1 cm depth, using two polycarbonate pillars (*Fig. 1c*). The IPG was placed at nearly 6 cm from the top edge of the "body", at 1 cm depth (*Fig. 1b*). This position mimics the shoulder/IPG distance in the patient. Four fiber-optic temperature sensors (Photon Control®, precision ±0.2K) were placed in the gel: the first (I) on the IPG; the second (II) at the left side of the body, opposite to the first, for control; the third (III) and fourth (IV) on the proximal and distal stimulation contacts, respectively. The phantom was placed in a 3-T TX Achieva MR scanner (Philips Healthcare®) such that the junction between the "head" and "body" parts of the phantom was located at the isocenter (*Fig. 1a*, dark line). The system body coil was used for RF transmission, on Multi-Transmit with a RF-Shim in quadrature. We ran three sequences of varying SAR for heating which features are: a T1-TFE sequence for survey, of 87s duration, B_1^{RMS} of 0.92µT and a SAR<0.1W/kg; a B_1 calibration sequence of 31s duration, B_1^{RMS} of 0.90µT and a SAR<0.1W/kg; and finally a high-SAR TSE scan of 730s duration, B_1^{RMS} of 2.27µT and a SAR<1.7W/kg.

Results and Discussion

Fig. 2 presents the E-field obtained from the EM simulation, in V/m. It shows that the electrical field is the highest at the corner between the "head" and "body", where field lines are focused. The passage of the VNS extension lead in this area thus indicates a risk of strong heating due to RF-induced currents in the device. *Fig. 3* shows the corresponding E-field map in a realistic human body model. There are quantitative differences between the human model and the phantom, but the E-field hot-spot in the neck area, where the extension lead is passing, is observed in the human model as well. The strong gradient of E-fields indicates that the actual heating observed may be very sensitive to the exact electrode position. *Fig. 4* shows the RF heating measured in the actual phantom experiment with the VNS device. During the two first scans up to t=300 s (survey and B_1 calibration), the heating was less than 0.3 K for all four probes. For the probes III and IV, the temperature increase reached 3.5 K during the TSE sequence, whereas probe I situated on the IPG presented a temperature rise of less than 0.5 K. The reference probe II had a low constant temperature increase. Four other configurations (landmark position/IPG position), were also examined in phantom experiments (data not shown), and found to result in lower temperature increases than the one presented here. Due to experimental limitations, it was not possible to fix a temperature probe in the small container opposite to the VNS tips. Despite this fact, by plotting an asymptote at the end of the main heating, the background temperature increase around the tips could be extrapolated to be close to 0.5 K. Thus, the maximum heating at the electrode tips was more than 6 times higher than in absence of the VNS device.

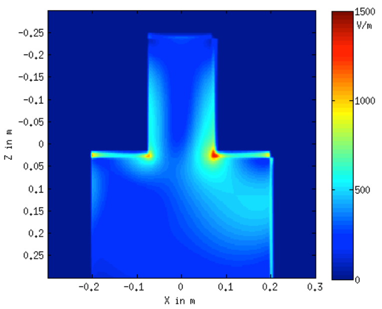

Fig. 2: Simulated E-field map in the coronal plane containing the VNS lead in the experiment.

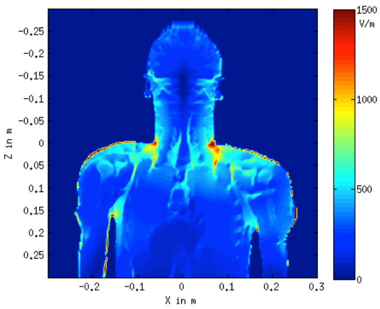

Fig. 3: Simulated E-field map a human body model.

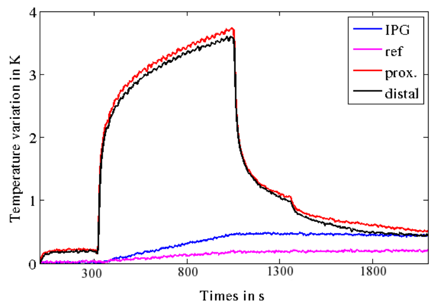

Fig. 4: Temperature variation in K during the experiment measured at four locations

Conclusion:

A temperature increase of 3.5 K at the tip of the VNS device was observed in phantom experiments, showing a significant risk for RF heating at high SAR level. The EM simulations show a strong electric field gradient in the neck region, implying that heating will strongly depend on the exact implant and sample configurations. Appropriate safety factors should thus be taken into account when predicting heating in a patient. The most realistic heating predictions may be achievable with realistic numerical simulations, for example using The Virtual Family models [3], covering a wide range of configurations.

References: [1] George and al., Neuropsychopharmacology, **35,** 301-316 (2010). [2] Gorny and al., J. Magn. Res. Imag., **31**, 475-481 (2010). [3] Virtual Family, IT'IS Foundation, Zürich, Switzerland. [4] ASTM, F2182-09. This work was supported by a grant from the Rhône-Alpes Region.