Investigation on RF Heating of Standard Implants in a Gel Phantom during MRI with a 1.5 T MR System (GE Medical Systems)

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Purpose

Significant radio frequency (RF) heating effects at implants can occur during magnetic resonance imaging (MRI) and are based on the interaction of the electromagnetic environment of the MR scanner with electrically conductive structures of implants. This interaction is a complex multiparameter dependent issue and influenced by the special MR environment, the implant's geometry and position within a patient and relative to the MR coil, but also on electrical properties of the tissue and the implant material. In order to investigate the complex interaction, the US FDA has started an interlaboratory comparison study. The aim is to investigate the significance and reliability of the whole body averaged (WBA) software displayed specific absorption rate (SAR) in terms of RF heating of implants between different 1.5 Tesla MR systems. In this part of our contribution to this study we investigated two implants positioned within a phantom at three phantom landmark positions relative to the MR coil. After the experiments, a numerical investigation by computer simulation of SAR distribution was done.

Material and Methods

A 1.5 Tesla MR system with Echospeed gradient system up to 33 mT/m and 120 T/m/s slew rate was used (Signa Excite, General Electric Medical Systems, Milwaukee, USA). RF was transmitted via the body coil. A Fast Spin Echo sequence with the following adjustments was applied: TE = 14 ms, TR = 1734 ms, FoV = 480 x 480 mm/ 128 x 128 pixel, FA = 90°/180°, half bandwidth = 31.25 kHz, slice thickness = 4 mm, slices = 36, orientation: coronal, echoes (ETL) = 61, NEX = 14, phase encoding: S/I, software reported: estimated (WBA) SAR = 1.9074 W/kg, Peak SAR = 3.8148 W/kg, duration = 30:03 minutes. A 4 channel fiber optic thermometer (Optocon, Germany) was utilized. A 45 kg human torso shaped phantom (≈ 150 mm gel depth) (FIG. 1) with styrolene insulation was used. The temperature probes P1 to P4 were placed within the phantom (Phase 2) and at the ends of the implants (Phase 3) in tangential and perpendicular orientation. Two generic implants (200 mm x 1 mm in ∅) made of stainless steel with insulation and bare ends were fixed in the middle of the gel height and in head and torso position parallel to B_0. Three phase were run: Phase 1 "calorimetry test", Phase 2 "temperature distribution" without implants and Phase 3 "implant heating" at three landmark isocenter positions of the phantom L1 to L3. The pulse sequence was stopped in Phase 3 after 10 minutes. The phantom was filled with 0.25% NaCl solution for Phase 1 and for Phase 2 and 3 with gel: dist. water; 1.4 g/L NaCl; 10 g/L poly(acrylic acid), Aldrich, USA) simulating the electrical and thermal properties of the human body. "72 kg" and "40 year old" was used for phantom registration. The phantom temperature was cooled down and homogenized before each MR scan. The numerical investigation was done by using simulation software (Ansoft, USA) and experimental testing data as input. The SAR distribution was calculated for phantom and implants.

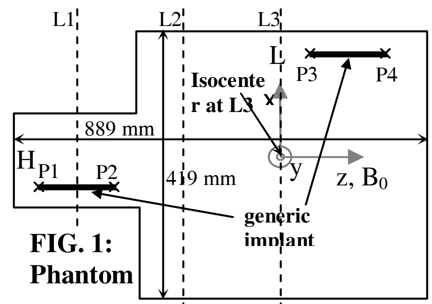

FIG. 1: Phantom

Results

Landmark position	T prior [°K]	T after [°K]	Calorimetry WBA SAR	Est. (WBA) $SAR_{software\ displayed}$ [W/kg], 80 kg volunteer	Est. (WBA) $SAR_{software\ displayed}$ [W/kg], Phase 1	Est. (WBA) $SAR_{software\ displayed}$ [W/kg], Phase 2	Est. (WBA) $SAR_{software\ displayed}$ [W/kg], Phase 3
L1	21.10	21.43	0.7655	2.0063	1.9074	1.9074	1.9074
L2	21.40	22.05	1.5078	2.0063	1.9074	1.9074	1.9074
L3	21.05	21.90	1.9717	2.0063	1.9074	1.9074	1.9074

Tab. 1: WBA SAR results of Phase 1 "calorimetry" and software displayed Est. (WBA) SAR for the volunteer and Phase 1 to 3

	Phase 2 "temperature distribution", Scan time 30:03 min., no implants, probes distributed in phantom head and torso			Phase 3 "implant heating", tangential probe positioning Scan time 10:00 min., probes at implant ends			Phase 3 "implant heating", perpendicular probe positioning, Scan time 10:00 min., probes at implant ends		
Landmark position	L1	L2	L3	L1	L2	L3	L1	L2	L3
Temperature probe	Temperature rises (average values) [°K]								
P1	0.47	0.16	0.00	7.25	2.96	0.07	6.49	2.96	0.11
P2	0.60	0.39	0.00	9.01	4.79	0.20	8.66	5.56	0.30
P3	0.18	0.24	0.09	0.40	4.23	33.07	0.43	5.39	33.21
P4	0.13	0.01	1.18	0.38	2.19	24.90	0.30	2.68	24.19

Tab. 2: Temperature rises of Phase 2 without implants and Phase 3 with implants

The calorimetry test at L3 showed a WBA SAR, which was close to the software displayed SAR. If moving the phantom into the body coil towards the head, the SAR is increasing. However, the software displayed WBA SAR was in each landmark and coil load configuration the highest displayed during this test. The same WBA SAR displayed was also detected for a volunteer, slightly higher in weight as the phantom registration and thus receiving a higher SAR. The distribution of the temperature increases in Phase 2 relative to the landmark has a similar characteristic as the geometric distribution of the probes within the phantom. The heating of the implants was detected to be maximal if the effective area of the RF coil covered the phantom section of the implant locations. The temperature increase was higher for the same implant length in the torso section compared to the implant within the head section. The highest temperature rise detected is ≈ 33°K for the landmark position L3 and probe P3, torso implant, bare end towards the middle. The local SAR of this implant ending corresponding with the temperature increase is approximately 230 W/kg if using a linear estimation. The computer simulation provided results of the same characteristics for the implant heating at each end (Fig. 2). However, the coil dimension was assumed to be infinite and thus the position dependency of the phantom was not depicted.

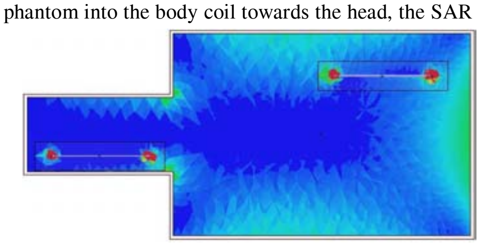

Fig. 2: quantitative results of numeric investigation; SAR distribution at the implants and within the phantom (red high values, blue low values)

Conclusion

This investigation has shown, that MRI can cause significant heating on electrically conductive structures. Especially it has shown that this interaction is dependent on the implant position relative to the MR coil and within the phantom. The WBA SAR is covering from a safety perspective the power absorbed within the phantom without implants, but the WBA SAR is inappropriate to make safety estimations about implant heating as this would need to concentrate on local SAR. Computer simulation provides comprehensive information and will help in future to assist in worst-case determination for experimental testing.