RF safety aspects for hip implants during MRI: A comparison between numerical calculations and experimental measurements

D. Li[1], J. Stenschke[1], M. Thomann[2], X. Zhang[1], G. Schaefers[3], and W. Zylka[4]

[1]Medical Physics, University of Applied Sciences Gelsenkirchen, [2]Medical Physics, University of Applied Sciences Gelsenkirchen, NRW, Germany, [3]mr:comp GmbH, Gelsenkirchen, Germany, [4]Medical Physics, University of Applied Sciences Gelsenkirchen, Gelsenkirchen, NRW, Germany

1. Introduction

Attempts to ensure RF safety in MRI often rely on assumptions about local temperature from local SAR levels. In case of patients with implants calculations of temperature may be preferable to calculations of SAR because of the more direct relationship between temperature and safety.

The precise relationship between SAR and temperature is multifactorial. More often patients who have had a total arthroplasty have an MR examination. A feeling of pain or heating during an MR scan is stated by some of the patients, with orthopedic implants [1]. Motivated by a FDA report of a patient with bilateral hip prosthesis who received burns on the inner thighs [2], we investigated RF heating within a phantom model of titanium hip prostheses (THP). A numerical model was developed containing a hip prostheses implant during radio frequency deposition in MRI. Calculations of SAR and the resulting temperature increases were performed for B_0=1.5T. Comparison of experimental measurements yields good qualitative agreement.

2. Materials and Methods

To estimate SAR, full-Maxwell equations calculations of absorbed power were performed for phantom models. A rectangular phantom was modelled according to the ASTM standard [3]. Experimental data were obtained with this phantom and a THP placed on a specific position.

As the static field B_0 and the gradients do not induce relevant deposition of energy in tissue, they have neglected. The B_1 field was assumed to be a circular-polarized wave. This corresponds to an ideal illumination of an ideal coil. The magnitude B_1=12µT is determined by the maximum of the experimental RF pulse. The effective duration of the RF exposure was 68.43s, only 180° pulses were taken into account. For the delimitation of the environment, a radiation boundary was used which absorbs the wave, essentially ballooning the boundary infinitely far away from the phantom structure.

Numerical calculation of temperature changes are based on the bio-heat equation by Pennes [5]. Thermal source was modelled as the SAR value calculated by solving Maxwell equations. The exposure to the electrical fields was one continuous pulse set to the effective RF exposition time. All numerical investigations were performed using HFSS and ePhysics (Ansoft, USA) [4]. Following experimental setup data were used as additional input for the numerical calculation. The MR examination was done on a 1.5T MR-system (Intera, Philips) with Turbo Spin Echo, TE=60ms, TR=6190.6ms, FA=90°, max. B_1=26.10µT. A 4-channel fiber optic thermometer (Optocon, Germany) was utilized. A gel phantom was used. The upper thighs were separated by an inserted 'crotch' (60x173x200mm) of styrolene material fixed with silicone. A total hip prosthesis (THP) (Plus Orthopedics, Switzerland) consisting of a titanium shaft and cup with polyethylene inlay and a stainless steel ball.

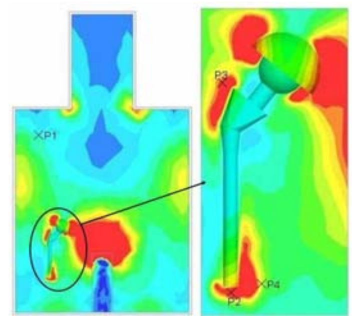

Fig. 1. *Cross section of the local temperature (25°C to 27.5°C).*

3. Results and Discussion

The relationship between local SAR levels and local temperature is not, however, straightforward. Numerical calculations confirms the theoretical power law SAR~$(B_0)^2$ but not SAR~ΔT. Instead, in the local hot spot SAR~$\Delta T^{1.6}$ was observed. Thus, calculations of temperature may be preferable to calculations of SAR as an expression of a more direct relationship between temperature and safety. The numerical calculated temperature map was used to select points of interest for measurements, i.e. significant change in temperature, see Fig. 1. The polystyrene block favours the energy deposition in the central part of the phantom. Thus a temperature increase at the hip prostheses pan develops. Figure 2 shows a comparison of measurements and numeric calculations at point P2. The difference of 2.25% between numerical solution and experiment is attributed to the simplified numerical model and not ideal experimental conditions.

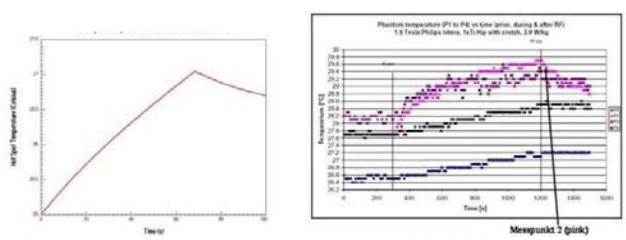

Fig. 2. *Numerical and experimental results for the temperature at P2.*

4. Conclusions and Open Questions

SAR levels and temperature increases in phantoms are subject to phantom geometry, homogeneity and material. There is not good spatial correlation between SAR and temperature increase, the physiologically relevant parameter in evaluating risk of MR examinations. This is a result of the multifactorial relationship between SAR and temperature. It is apparent from numerical results and comparison to experimental results that implants provide a relatively efficient conductive heat transfer to the surrounding tissue. Although global or local SAR levels may be a simple straight forward approach, predication of temperature increases remains more relevant in terms of safety. It is noteworthy that there is a need a further refinement with respect to RF coil and MR sequence model. The use of phantoms is an intermediate step. A general approach addressing individual patient, potentially with implants, especially in high field MR examinations, remains an aim for the future.

Acknowledgements. The authors thank Markus Laudien from Ansoft Europe for continuing support and ePhysics license key.

References

1 FDA-Medical-Device-Reporting Database, ACCESS NUMBER: M375292.
2 FDA-MAUDE-Database, MDR Report Key 469680.
3 ASTM F2182-02a Standard Test Method for Measurement of Radio Frequency Induced Heating Near Passive Implants During Magnetic Resonance Imaging
4 Ansoft Inc. HFSS V9.2 Online-Help.
5 H.H. Pennes, J. Appl. Physiol., 1, 93, 1948.