A novel phantom design to reduce thermal losses during radio frequency (RF) induced heating testing according to ASTM F2182-09 standard

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Introduction

An accurate measurement of averaged temperature rise is important for calculating the averaged SAR. Today, required thermometer resolution of 0.05° determines the accuracy of heating measurements. With the change from ASTM F2182-02a to F2182-09 standard [1] thermal insulation of the phantom gel/saline used for RF heating experiments became mandatory. The standard demands an insulating shell using a material with a thermal conductivity of less than 0.029 W/m*K (R-value 5.0 ft^2*h*°F/Btu). As an example wall thickness of 25 mm or more of extruded polystyrene is mentioned. However, not only thermal energy loss to the surrounding of the phantom is causing an error, but also the thermal capacity of the phantom construction material itself (usually PMMA of ≈ 10 mm). Especially, because the largest temperature rises are located next to the phantom wall (skin effect).

Material and Methods

A “conservative” phantom with 8 mm wall thickness and 10 mm ground plate (PMMA) was compared to the novel “progressive” sandwich design. This consisted of a thin inner phantom and a thermally insulating layer as well as an outer phantom providing mechanical stability. Both designs are filled with a saline solution having the same electrical and thermal properties. Simulations have been done for 64 and 128 MHz (results the later are not presented in this abstract) using the FDTD [2] method implemented in SEMCAD X 14.2.1 for obtaining the SAR distribution and the phantom averaged SAR inside a generic birdcage body coil. Subsequently thermal simulations were run using the same grid applying the simulated electro dynamical results as heating source [3]. After 20 minutes of simulated heating the mean temperature rise (resembling condition after stirring) was used to calculate the mean SAR with SAR = $c_p*\Delta T/\Delta t$. Results were compared to the mean SAR of the electro dynamical simulations. Insulating boundary condition was used for phantoms and saline relative to the background of the simulation domain. Effects of convection, thermal radiation and stirring of the phantom saline are not considered. Thermal conductivity was 0.6 W/m*K for saline and 0.19 W/m*K for PMMA. The approach was validated by calculating the temperature rise of the saline solution along with surrounding isolating boundary conditions (for both associated SAR distributions as heating sources) but not including the phantom container. A configuration where a stirring mechanism remained inside the phantom during heating was also simulated.

Results and Discussion

The table below shows an obvious reduction of thermal energy loss to the phantom material when using a thinner phantom wall. With 0.067°C (for a mean SAR of ≈ 4 W/kg after 20 minutes) the error could be above the demanded resolution (0.05°C) of the thermometer used for calorimetric determination of whole phantom SAR when using a “conservative” design. Using the improved “progressive” layout this is reduced to 0.026°C.

64 MHz, insulating boundary condition	Saline mean SAR [W/kg]	Saline mean ΔT [°C]	Calculated SAR from mean temperature rise [W/kg]	Difference [W/kg]	Error [%]
Insulated saline only for method validation (progressive)	4.00145	1.15423	4.001330667	0.000119333	**0.00%**
Insulated saline only for method validation (conservative)	4.00021	1.15388	4.000117333	9.26667E-05	**0.00%**
Novel progressive sandwich phantom filled with saline	4.00145	1.12784	3.909845333	0.091604667	**2.29%**
Conservative phantom filled with saline	4.00021	1.08727	3.769202667	0.231007333	**5.77%**
Progressive phantom with stirring mechanism and saline	4.01539	1.12900	3.913866667	0.101523333	**2.53%**

TAB. 1: Thermal error simulation for phantom designs at 64 MHz

Conclusion

The simulations have shown that the thermal error of a phantom can be reduced from 5.77% to 2.29% by simple design modifications without using other potentially more expensive materials or thicker insulating layers. While further reduction of wall thickness of the inner phantom or total removal would provide even better results, requirements of mechanical and moisture protection require keeping it at a reasonable but minimized thickness. It has been found that the error caused by thermal capacity of the material and by the shape of phantoms used today to measure RF heating is possibly bigger than the influence of thermal loss by the insulating shell.

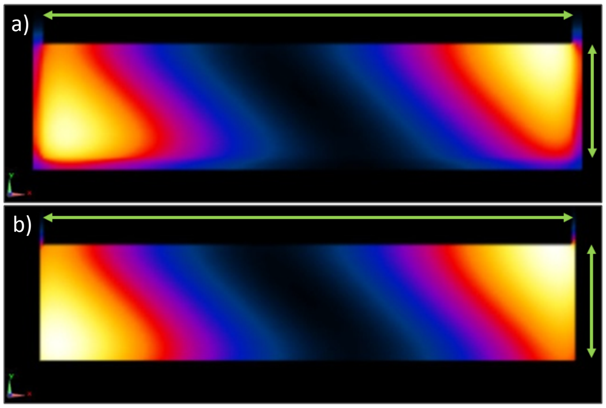

FIG. 1: Temperature distribution (transversal mid slice) after 20 minutes of simulated heating at 64 MHz for a) “conservative” and b) “progressive” sandwich phantom design. Green arrows show dimension of saline volume.

References

[1] ASTM INTERNATIONAL, Standard Test Method for Measurement of Radio Frequency Induced Heating On or Near Passive Implants During Magnetic Resonance Imaging, 2009.

[2] S. Hagness A. Taflove, *Computational Electrodynamics: The Finite Difference Time Domain Method*, Second Edition ed.: Artech House Publishers, 2000.

[3] Suhas V. Patankar, *Numerical Heat Transfer & Fluid Flow*.: Taylor & Francis Inc, 1980.