Reduction of Implant RF Heating by Modification of Electric Field Distribution

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Introduction

Radiofrequency (RF) heating at the tip of metallic wires is a significant safety problem in MRI. Radiofrequency electric fields induce currents on metallic wires. These currents flow through the body and cause SAR amplification near the wire tip. Most popular approaches for preventing wire tip heating depend on modification of implant lead designs [1]. Some of these designs are based on placing lump elements such as RF chokes and resistors on the lead wires [2]. This makes it difficult to produce mechanically robust leads. On the other hand, for the patients who already live with pacemakers, the exchange of old fashioned leads with modified safe ones may not always be plausible. In this study it is shown that lead heating may also be prevented by modifying the electric field while keeping the magnetic field distribution unchanged.

Theory

In the standard quadrature birdcage coils electric field is uniform in the angular direction, but varies roughly linearly in the radial direction. Therefore an implant lead placed at the edge of the body experiences high electric field. On the other hand the electrical field in a linearly polarized birdcage coil varies sinusoidally in the angular direction. Therefore for this tyoe of coils there is a plane where the electric field is zero. The angle of this plane can be steered to any direction by modifying the orientation of the linearly polarized magnetic field. If the implant lead lies in this zero electric field plane there will be no induced current on the lead. A linearly polarized coil has an identical sensitivity as a quadature coil. However whole body average SAR is doubled. Therefore with this technique implant lead heating problem is solved with the cost of increased whole body SAR.

In order to alleviate the whole body SAR problem a general formulation is developed to keep the sensitivity uniform and electric field near the lead zero. The forward polarized field component H_f determines the sensitivity of the coil which can be set to unity without loss of generality. Using basis expansion of EM fields in cylindrical coordinates the constraints on electric and forward polarized magnetic field can be expressed as $E\alpha = \underline{0}$ and $B\alpha = c$ respectively. E and B matrices contain the values of cylindrical modes evaluated at desired sample points. The vector α denotes the weighting coefficients of the basis functions. c is the desired sensitivity and $\underline{0}$ is the zero vector. The two linear constraints can be combined into a single matrix equation as $F\alpha = e$ where F and e are simply formed by concatenating the matrices B, E and the vectors c , $\underline{0}$, respectively. Among infinite number of solutions that satisfies $F\alpha = e$ the one that minimizes whole body average SAR can be found by minimizing $\alpha^* R\alpha$. Here R is the electric field cross correlation matrix. The solution for α and the minimum whole body SAR in this case is $\alpha_{opt} = R^{-1}F^*(FR^{-1}F^*)^{-1}e$ and $SAR_{\min} = e^*(FR^{-1}F^*)^{-1}e$ respectively.

Methods and Results

In order to test the effectiveness of the method a gel phantom (radius 0.15m , conductivity 0.5 S/m) with a resonant length straight wire, is scanned by using a home made linear polarized birdcage coil using a GE 1.5T Signa system. SPGR sequence with flip angle=90 deg, TR=4.3msec was used. Experiment is repeated by placing the wire on two different perpendicular planes. Figure 1 shows the heating curves of the wire leads on two planes. Note that on the plane 1(blue) electric field is approximately zero as predicted, hence temperature rise is not observed. On the other hand for plane 2(red) the wire is heated 5 degrees in 500 seconds since electric field is significantly high on that plane. The same experiment is repeated using a GE quadrature head coil by placing a wire on the same two planes. In both planes a significant and similar temperature increase was observed.

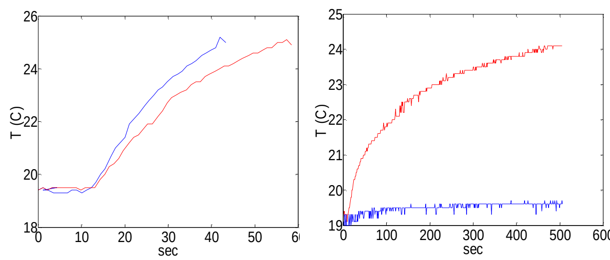

Figure 1 Heating curves of a resonant length wire placed on sagital and coronal planes of a home made linear polarized (a), GE quadrature (b) birdcage coil

A MATLAB (version 7.0,MathworksInc., Natick, MA) program is used to implement the field expansion in a homogenous body model of radius 0.15.m The conductivity, relative permeabilitiy and permittivity of the body model is assumed as 0.5 S/m, 1 and 70 respectively. H_f is set to unity in a target profile of radius 0.13 m is formed by sampling the profile in uniformly distributed points.(Figure 2) Radial and z directed electrical field components are set to zero in a rectangular region by using 20 sample points (Figure 2).

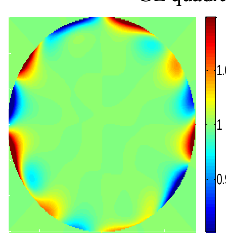

Figure 2 A uniform transmit target profile

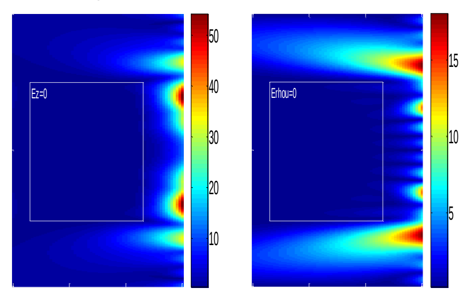

Figure 3 Electric field components E_z (left), E_ρ (right) can be equated to zero in a desired region on a sagittal plane

Discussion

Resonant length wires are placed close to gel-air boundary where the electric field is maximum in order to obtain significant heating. The similar heating reduction principles apply to wires with arbitrary shapes as long as they form a planar contour.

Conclusion

In this work it is shown that steering the electric field away from the implant lead may prevent heating.

Reference [1]C. J.Yeung,R. Susil,E. Atalar "RF Safety of Wires in Interventional MRI Using a safety Index" Magnetic Resonance in Medicine 2002:47:187-193 [2] O.Ferhanoglu,Y.Eryaman,E.Atalar "MRI Compatible Pacemaker Leads",ISMRM 2005 p 963