Local SAR Investigations in the Presence of Conductive Media

Craig I Lawrie[1], Xiaoyu Yang[1], Tsinghua Zheng[1], Matthew Finnerty[1], Shinya Handa[1], and Hiroyuki Fujita[1,2]

[1]Quality Electrodynamics, LLC, Mayfield Village, Ohio, United States, [2]Department of Physics, Case Western Reserve University, Cleveland, Ohio, United States

Target Audience: This study will be primarily beneficial to those whose research is in the area of MR safety, such as those investigating SAR safety with respect to conductive device leads, catheters, or guidewires; use of local transmit / transceiver coils to improve local SAR behavior; or computer simulations (FDTD) involving coil performance and SAR.

Purpose: The use of a local transmitter coil to reduce local SAR heating is evaluated with regards to MRI imaging in the presence of long conductive media. Previous investigations [2] have shown various possible heating mechanisms for conductive media used in an MRI environment. Among these heating mechanisms, the electric field antenna affect was shown to create significant heating near the end of a long conductive wire, especially when the length nears resonance [2]. Such long conductive wires can be found in the MRI environment in the form of leads to EEG [3] or other monitoring or multi-modality equipment, and in conductive catheters or guidewires used for image-guided interventional procedures [1,4]. The heating in such devices occurs at the tip of the long conductive medium [2], but the amount of heating is highly dependent on several factors, including the length of the conductive medium, the position within the MRI coil, and the dielectric constant of the patient or phantom [1-3]. Since the position within the coil and the amount of the conductive media positioned near a high dielectric patient are liable to change from one situation to another, it is important to find a solution that can be generally applied to improve SAR and heating characteristics. One possibility is the use of a local transceiver coil to reduce the total power and $\vec{E}$ field magnitude. This possibility is evaluated in the form of a simulation using commercial software (xFDTD, Remcom, State College, Pennsylvania, United States) to calculate SAR for various configurations of a coil and a representative wire.

Methods: A simulation model was generated as shown in Fig 1. A perfect electrical conductor wire was constructed parallel to the $\vec{B}_0$ field, and positioned such that one end was centered in the $\hat{z}$ direction. Two different transmit coils were constructed using birdcage geometry: a large 'whole body coil' (WBC) and a small 'local transmitter coil' (LTx). These transmitter coils were built of perfect electrical conductors and driven at $63.6MHz$. In both cases $n_{rungs} = 16$. Birdcage dimensions are $dia_{WBC} = 60cm$, $l_{WBC} = 130cm$, $dia_{LTx} = 40cm$, and $l_{LTx} = 50cm$. A cylindrical phantom was centered in the coil such that $dia_{phantom} = 30cm$, $l_{phantom} = 130cm$, $\varepsilon_{r,phantom} = 60$, $\sigma_{phantom} = 1\,S \cdot m^{-1}$, and $\rho_{phantom} = 1000kg \cdot m^{-3}$. Finally, a large cylindrical bore of $dia_{bore} = 63cm$, $l_{bore} = 130cm$ was positioned around the model to represent the shielding conditions of the gradient ciol. Simulations were then run for both coils with the wire centered in the $\hat{x}$ and $\hat{y}$ directions, and again with the wire offset by $10cm$. For comparison, the same coils were simulated with no wire at all.

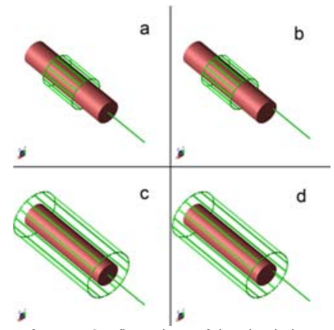

Figure 1 Configurations of the simulations described. (a,b) LTx coil 40cm diameter, 50cm length; (c,d) WBC 60cm diameter, 130cm length. (a,c) wire centered; (b,d) wire off-center.

Results: All simulation outputs were scaled such that the rotating $\vec{B}_1^+$ field was equal to $1\mu T$ at isocenter. As expected, when the wire was centered in $\hat{x}$ and $\hat{y}$, there was no noticeable effect on the local SAR distribution, and when the wire was off-center by 10cm, there was a dramatic increase in local SAR at the tip of the wire for both coils. The maximum local SAR values for these configurations are displayed in Table 1 and distributions are shown in Fig 2. The rotating $\vec{B}_1^+$ field for the axial slice through isocenter is shown in Fig 3, and the $\vec{E}$ field magnitude for the coronal slice is shown in figure 4.

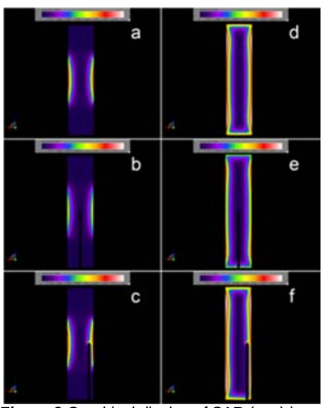

Figure 2 Graphical display of SAR (raw) in the coronal slice through the conductive wire. (a) LTx no wire (b) LTx wire centered (c) LTx wire off-center (d) WBC no wire (e) WBC wire centered (f) WBC wire off-center. Scale: 0 W/kg – 2 W/kg

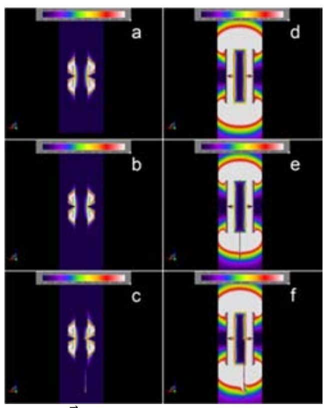

Figure 3 $\vec{E}$ field magnitude in the coronal slice through the conductive wire. (a) LTx no wire (b) LTx wire centered (c) LTx wire off-center (d) WBC no wire (e) WBC wire centered (f) WBC wire off-center. Scale: 15 V/m – 75 V/m

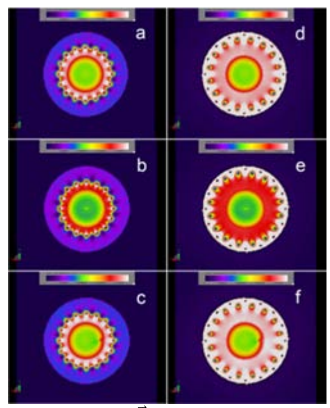

Figure 4 Rotating $\vec{B}_1^+$ field in the axial slice through isocenter. (a) LTx no wire (b) LTx wire centered (c) LTx wire off-center (d) WBC no wire (e) WBC wire centered (f) WBC wire off-center. Scale: 0μT – 2μT

	Max SAR (W/kg)		
Configuration	Raw	1g avg	10g avg
LTx, no wire	1.764	1.658	1.479
LTx, wire centered	1.293	1.216	1.084
LTx, wire off-center	5.221	2.118	1.793
WBC, no wire	2.456	2.315	2.056
WBC, wire centered	1.792	1.691	1.496
WBC, wire off-center	5.539	2.912	2.623

Table 1 Maximum SAR values for each configuration. Max SAR values for 'wire centered' configurations are located at the outer surface of the phantom. Max SAR values for 'wire off-center' configurations are located at the tip of the wire.

Discussion & Conclusion:

The results indicate that a local transmitter coil has a significant advantage for two reasons. Firstly, it is apparent that the peak SAR is lower for the local transmitter coil compared to the whole body coil. This can be easily explained by the fact that a smaller, more locallized transmitter coil requires less total power in order to generate a certain magnitude of $\vec{B}_1^+$ at the region of interest compared to a larger coil. Secondly, it is apparent that there is little to no SAR increase if the conductive wire is positioned near low $\vec{E}$ field regions. This is a clear advantage to split-design local transmitter coils, such as an anterior-posterior Helmholtz coil pair that can be positioned with the minimum $\vec{E}$ field aligned with the actual conductive medium used.

References:

[1] Ladd, M.E.; Quick, H.H.; Boesiger, P; McKinnon, G.C. RF Heating of Actively Visualized Catheters and Guidewires. In: Proceedings of the 6th Annual Meeting of ISMRM, Sydney, Australia, 1998; 473.

[2] Dempsey, Mary F; Condon, Barrie; Hadley, Donald M. Investigation of the Factors Responsible for Burns During MRI. J Magn Reson Imaging 2001; 13:627-631.

[3] Nöth, Ulrike; Laufs, Helmut; Stoermer, Robert; Deichmann, Ralf. Simultaneous Electroencephalography-Functional MRI at 3 T: An Analysis of Safety Risks Imposed by Performing Anatomical Reference Scans With the EEG Equipment in Place. J Magn Reson Imaging 2012; 35:561-571.

[4] Ladd, M.E.; et al. Active MR Visualization of a Vascular Guidewire In Vivo. J Magn Reson Imaging 1998; 8:220-225.

Acknowledgements:

The authors thank Dr. Anthony Faranesh and colleagues at NIH/NHLBI for discussions and collaboration in related projects.