Effect of Deep Brain Stimulation lead resistivity on specific absorption rate at 3 T MRI

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INTRODUCTION. Deep brain stimulation (DBS) is a surgical procedure currently used on over 30,000 patients in US to treat symptoms linked to Parkinson's disease. MRI is often the diagnostic tool of choice for monitoring many pathological changes in many Parkinson's patients with an implanted DBS system. These patients may also undergo investigational functional MRI (fMRI) [1]. However, the radio frequency (RF) field may produce excess heating in presence of DBS leads [2]. Unfortunately, a case of serious neurological injury from RF heating occurred recently during a clinical MRI investigation on a patient with an implanted DBS system [3]. Given the known relationship between SAR and heating [4], the effects of DBS lead resistivity were evaluated in terms of specific absorption rate (SAR).

METHODS. Numerical simulations based on the FDTD algorithm [5] were performed on an anatomically fine-grained head model [6] with electrical properties selected as in literature [7]. Simulations were conducted using a birdcage RF coil (**Fig. 1**) [8] at a frequency of 128 MHz - 3 T. Following the standard setup for DBS implant [3], a DBS implant was modeled as a thin wire connected to the left sub-thalamic nucleus (**Fig. 1A**). The implant was oriented vertically through the brain, tunneled around the skull (**Fig. 1B**), and placed between the dura and bone, exiting at the base of the neck (**Fig. 1C**). The total length of the lead was 613 mm. Four different values of lead resistivity were evaluated: $\rho_{lead} = 1.67 \cdot 10^{-8}$ (ρ_{copper}), 10^{-5}, 10^{-3} and 1 Ω m. Whole-head, peak 1g and 10 g averaged SAR [9] were computed using the XFDTD software (REMCOM Co., USA) and values were normalized to 1 W of input power [10].

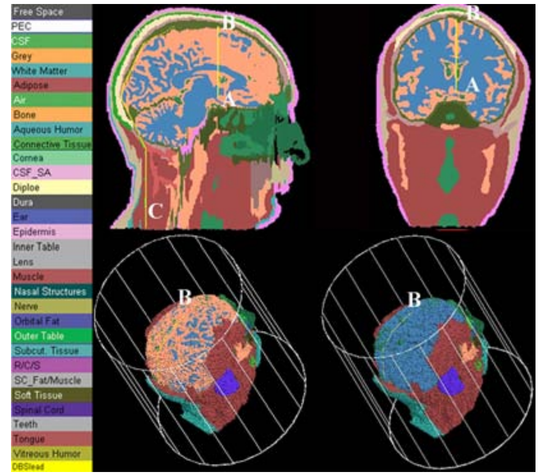


Figure 1. *2D and 3D view of head model with a co-registered DBS implant (yellow). (Bottom) 3D views of the head model and DBS implant, with illustrative view of internal tissues.*

RESULTS. Overall, simulation results confirmed that the resistivity of the DBS leads influenced both whole-head and peak SAR values. The DBS lead induced high values of SAR for low lead resistivity (ρ_{lead} equal to ρ_{copper}); SAR decreased as lead resistivity increased from ρ_{copper} to ρ_{lead} = 1 Ω m. There was a reduction in 1g averaged SAR of more than twofold when lead resistivity varied from $\rho_{lead} = \rho_{copper}$ to $\rho_{lead} = \rho_{ref}$ (see **Fig.3**). The relationship of SAR with resistivity can be approximated with a sigmoid function [10]: $\Sigma_f = \Sigma_0 + A\Big/\left(1 + e^{\rho_{lead}/\rho_0}\right)$ where [Σ_0, A, ρ_0] were found using least square fitting minimization for whole-head SAR, 1 g (red line in **Fig. 3**), and 10 g (green line in **Fig. 3**).

DISCUSSION AND CONCLUSIONS. The use of a head model with high spatial resolution and high anatomical accuracy allowed for evaluation of SAR in thin head tissues. Staircasing errors of approximately 20% [11] may be present due to the geometry of the model. Hence, this study was performed by varying only the lead resistivity and keeping unchanged the overall geometry of head, coil, and lead.

The simulations presented in this study suggest that the SAR of the human head at 3 Tesla varies as a sigmoid function with the resistivity of the DBS lead. The SAR changes are highest for low resistivity (copper) and are minimal for high resistivity values (i.e., $\rho_{lead} > \rho_{max} \approx 0.001$ Ω m). New and potentially safer leads with higher resistivity can be built for instance by employing conductive ink technology [12]. A new type of lead, the resistive tapered stripline, with low resistivity at low frequency and high resistivity at the RF frequencies has been investigated [13].

The main issue with highly resistive leads is the power deposition during normal operation. Considering that DBS systems are designed to include light and portable batteries, the power dissipated by the stimulating current must be minimized in order to extend battery life. For example, commercially available nylon-based fibers with copper coating with resistivity $\rho \approx 0.1$ Ω m may produce a good protection against risk, but power dissipation in the wire of several mW (**Fig. 3**). The sigmoid function can therefore be interpreted as a risk/cost function: the optimal value of resistivity ($\rho_{lead} = \rho_{max}$ in **Fig. 3**) will minimize both SAR dissipation at RF and power dissipation for the DBS system. Manufacturers of DBS devices are currently using metallic and highly conductive leads operating at the point of the curve with highest risk and lowest cost.

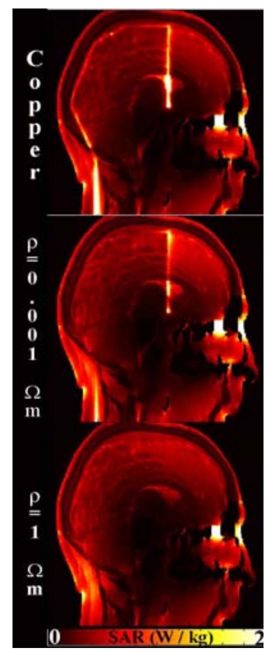
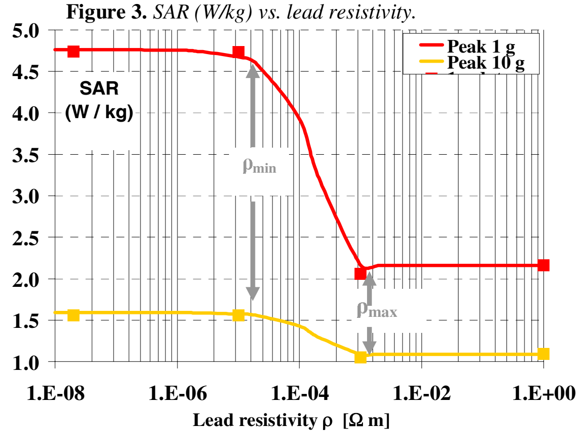


Figure 2. *SAR for DBS copper and high-resistivity lead.*

Figure 3. *SAR (W/kg) vs. lead resistivity.*



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