

# An MR Thermometry-GBHTM ‘Hybrid’ Model to Determine Radiofrequency Heating near Implanted Leads in High Field Imaging

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**Introduction** A validated tool is needed to image radiofrequency (RF) heating near implanted conductive devices in patients undergoing magnetic resonance imaging (MRI) in high fields to ensure/verify safety after a sequence. Clinically harmful RF heating near conductive implanted devices is a safety concern in high field MRI.

MR thermometry methods are regularly used to image in vivo temperatures; however, these methods are ineffective next to conductive devices due to susceptibility artifacts. A new theoretical bioheat model the generic bioheat transfer model (GBHTM) (1) has recently been developed and validated to determine in vivo RF heating in ultra high fields; however, the model requires RF power density in the device or the boundary temperatures near the conductive device as inputs to simulate RF heating next to the device. Due to the ability to provide complementary pieces of information by the MR thermometry (i.e., temperatures outside the artifact region) and the GBHTM (i.e., temperatures inside the artifact region) the two methods are combined herein to develop a novel ‘hybrid’ model to determine RF heating around a conductive device and evaluate patient safety right after an imaging sequence, while the patient waits in the scanner. The new ‘hybrid’ model is validated in a uniform gel phantom implanted with a deep brain stimulation lead in 3T.

**Experiment design and Methods** A deep brain stimulation (DBS) lead with four electrodes at the distal end was implanted in a cylindrical, uniform gel phantom. One fluoroptic probe each was taped to the two distal electrodes (i.e., electrodes three and four). Another fluoroptic probe was placed 5 mm away from the fourth electrode in the gel to validate MR thermometry outside the susceptibility artifact range. The instrumented cylindrical phantom was placed in a 3T, transmit and receive head coil. Next, a low whole head average SAR (<0.3 W/kg) gradient recalled echo (GRE) sequence was run to obtain baseline phase information near the device to conduct proton resonance frequency (PRF) shift based MR thermometry (scan time = 59 s). The susceptibility artifact range near the DBS lead for the GRE sequence was measured as ~5 mm. The GRE sequence was run again after a minute to determine the resolution of the MR thermometry method. Afterwards, an 8.57 minutes long turbo spin echo (TSE) sequence was run at the whole head average SAR of 3 W/kg to produce heating. Another GRE sequence was run right after the heating sequence to image temperature changes. The average imaged temperature change 5 mm away from the fourth electrode of the lead was used as input to the GBHTM. The GBHTM was used to predict the RF power density at the electrodes and the temperature changes in the susceptibility artifact range. The simulated temperatures were compared to the fluoroptically measured temperatures to validate the ‘hybrid’ model.

**Results and Discussion** Figures 1-4 present the implementation of the ‘hybrid’ model and its validation using fluoroptic thermometry in a cylindrical, uniform, tissue-mimicking gel phantom. Figure 1 presents the temperature change map before the TSE sequence (i.e., the temperature resolution map). The average temperature change for the whole slice was calculated as 0.15 °C. Figure 2 presents the temperature change map near the implanted DBS lead after the 8.6 min long TSE sequence at the maximum allowable whole head average SAR of 3 W/kg. The average temperature change of ~1.5 °C was imaged at the boundary of the susceptibility artifact range of the DBS lead (i.e., ~5 mm). The temperature changes at the electrodes and within 5 mm from the DBS lead could not be imaged reliably due to the susceptibility artifacts. Figure 3 shows that the GBHTM simulates the maximum temperature change of ~10.3 °C at the third DBS electrode and ~9.4 °C at the fourth DBS electrode after the 8.6 min long TSE scan for the maximum temperature change of ~1.5 °C 5 mm away from the fourth electrode. Validating the simulations, Figure 4 presents the fluoroptically measured temperature changes near third DBS electrode (maximum temperature change = ~10.3 °C), fourth DBS electrode (maximum temperature change = ~9.1 °C), and 5 mm away from the fourth electrode (maximum temperature change = ~1.5 °C) during the TSE sequence.

The maximum temperature change should be ~3.5 °C (i.e., absolute temperature <41 °C) in clinical settings near conductive devices to avoid stressing/damaging surrounding tissue. This three times reduced maximum heating near the electrodes will result in more than three times lower temperature change outside the artifact range due to blood perfusion (~0.5 °C) in a patient. Accuracy of the PRF based in vivo MR thermometry has been shown to be > 1°C. This underscores the need for developing very accurate MR thermometry technique to image temperatures outside the susceptibility artifact range with accuracy better than 0.1 °C to satisfactorily implement the presented ‘hybrid’ technique. Exogenous contrast (e.g., TmDOTA) based MR thermometry may need to be used to measure accurate temperatures (2).

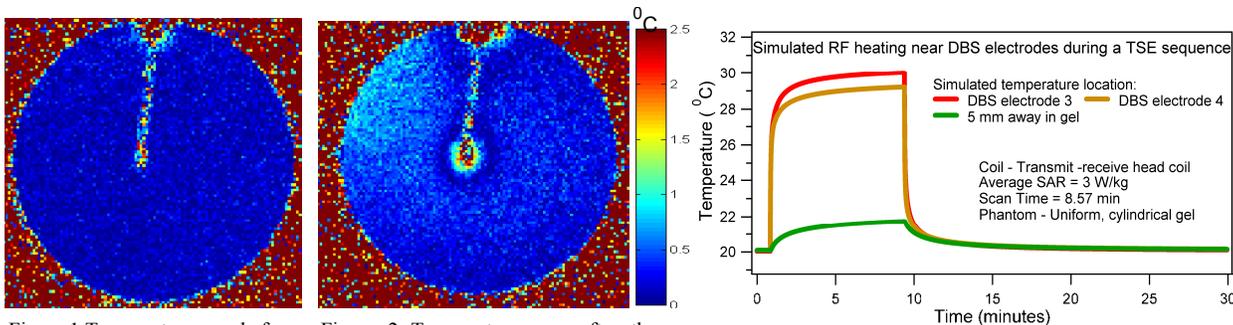


Figure 1 Temperature map before the spin echo sequence.

Figure 2 Temperature map after the spin echo sequence. RF heating near DBS lead electrodes was imaged outside the susceptibility artifact range.

Figure 3 MR imaged temperatures were used as inputs to the GBHTM to determine RF heating near DBS lead electrodes in 3T.

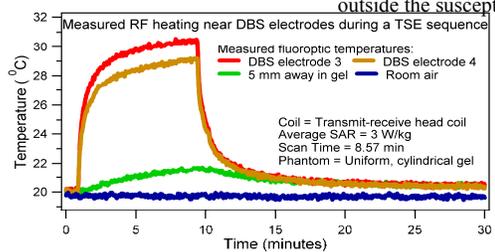


Figure 4 Fluoroptically measured RF heating at and near DBS electrodes during the spin echo imaging in 3T.

**Summary** An MR Thermometry -GBHTM based ‘hybrid’ model is shown to determine accurate RF heating at the electrodes due to imaging in 3T. Accurate and precise MR thermometry methods are needed to implement the new ‘hybrid’ model in vivo.

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**References** 1) Shrivastava et al., J Biomech Eng – T ASME 2009, 131(7):074506. 2) Hekmatyar et al., Int. J. Hyperthermia, 2002, 18(3), 165-179.