Functional MRI using implanted stereotactic EEG electrodes --- heating investigation for safety

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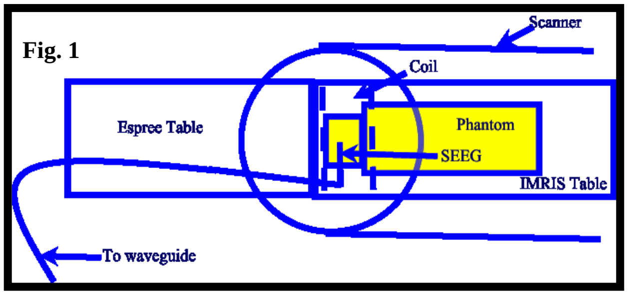
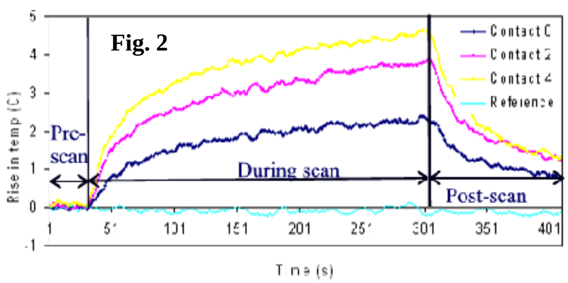
Target audience: Foundations of fMRI, epilepsy, stimulated electrode connectivity, intracranial electrodes

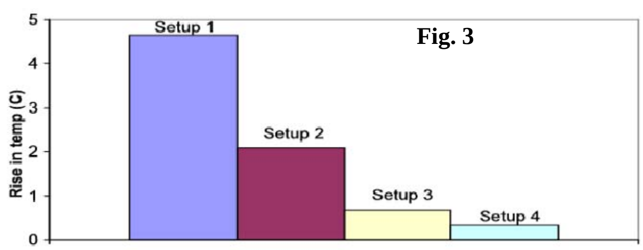
Purpose: Surgical resection of the epileptogenic zone (EZ) responisble for generating seizure activity[1] is a potential cure for medically refractory focal epilepsy. However, proper identification of EZ is essential for successful resection and our strategy for improving identification of the EZ is to interactively and synergistically apply a new functional MRI (fMRI) technique simultaneously with stimulation of multiple Stereotactic placement of intracranial EEG electrodes (SEEG)[2]. As a safety measure of performing MRI with implanted SEEG electrodes, we measured radio frequency (RF) induced heating of a SEEG electrode embedded within a phantom inside an intraoperative MRI suite, with the electrode directly connected to stimulus hardware located in the control room. The objective of the study was to investigate the effect on electrode heating by the geometry and configuration of the electrodes and associated connections. Once the safety of the procedure was ensured, fMRI scans were performed on human subjects with implanted SEEG electrodes as well.

Methods: A SEEG electrode (Add tech or Integra NeuroSciences, Plainsboro, NJ, USA) with 12 contacts was inserted in the head area of a torso phantom filled with polyacrylic gel[3]. The electrode was placed such that the distal point of contact corresponded approximately to the midline. Fluoroptic temperature sensors (model m3300, Luxtron, Santa Clara, CA, USA) were used for temperature measurement. The points of contact of the probes were contacts 0, 2, 4 (0 is the distal contact) and a reference point far away from the contacts. The SEEG electrodes were connected to a 2 ft long cable, which was connected to another long shielded (fiber-optic) cable. This cable was passed through a waveguide and connected to a S-88 simulator GRASS unit with PSIU6 constant current stimulus isolation unit. MR scans were performed using a 1.5 tesla Siemens Espree system (Erlangen, Germany) integrated with intraoperative MRI suite (IMRIS, Winnipeg, Manitoba, Canada) using a receive only split-array head coil. The phantom was put on the IMRIS table with the Espree table projecting out at the other side (Fig. 1), similar to the positioning of a human patient during intraoperative scanning. The configuration of the cable coming out of the scanner bore was varied from scan to scan in the following ways: Setup 1: the cable was allowed to lie directly on the Espree table; Setup 2: the cable was laid on a 0.5 cm above the table; Setup 3: the cable was laid 10 cm above the table;,Setup 4: the cable was laid 20 cm above the table. Multiple sequences were performed with continuous temperature recording, including sequences that would not be performed on a human in this setting but are known to produce the highest heating (T2 weighted TSE with TR/TE = 3700/118 ms, Flip angle (FA) = 180^0, Turbo factor = 15, echo trains per slice = 18). Different configurations included single SEEG electrodes and multiple SEEG electrodes (up to 12). Six intractable epilepsy patients with implanted SEEG electrodes were scanned using an fMRI sequence (TR/TE = 2000/50 ms, FA = 80^0, 160 repetitions). Brain slice from the left temporal lobe of one of the subjects was evaluated by a trained pathologist following the procedure using hematoxylin and eosin stain.



Results and Discussion: The temperature rise of three contact points on one SEEG electrode and reference point for Setup 1 is shown in Fig. 2. As much as 4.6^0C rise in temperature was observed, and the heating highest for those points farthest from the isocenter. As expected, no heating of the reference point was observed. The effect of different configurations of the connection cable on RF-induced heating is shown in Fig. 3. The heating is the highest with the cable lying directly on the table and decreases with the approach of the cable to the central axis of the bore. Usage of a receive only coil usually is expected to produce excessive heating because of the higher transmit power in comparison of using a transmit-receive coil. For TSE sequences, the computed whole body exposure, exposed body exposure and head exposure were 1.0, 1.5 and 1.1 W/kg, using an entered phantom weight of 90 kg. No significant heating was observed for any sequence (including TSE) when the cable was elevated more than 10 cm above the table. **While performing safety testing, the configuration should exactly match the setup to be used for surgical planning.** The brain sample evaluated by the pathologist showed no indication of any heat-induced damage.





Conclusion: RF-induced heating measurements of SEEG electrodes using a receive only split-array coil in an IMRIS system show that the temperature rise strongly depends on the geometry of cable connection to the SEEG electrode, with greatest heating along the floor of the bore. No significant heating was ever observed for cables laying close to the MRI's central axis, even for TSE sequences. This study supports safety feasibility of performing simultaneous intracranial electrode stimulation during an fMRI acquisition within an intraoperative suite. In addition, we were able to safely perform fMRI on patients with implanted SEEG electrodes as supported by pathologic finding.

References: 1. Luders, Epileptic Disord, 2006, S1-9
2. Gonzalez-Martinez, Epilepsia, Epub ahead of print, 2012.
3. Baker, J Magn Reson Imaging, 2006, 1236-42