Intracranial EEG in a High-Field MRI Environment: Safety Evaluation

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Background

Given the signal-to-noise advantages of high field magnetic resonance imaging (MRI), the integration of intracranial electroencephalography (EEG) with high field MRI may help elucidate mechanisms underlying neurological disease; however, introducing intracranial EEG electrodes into the MR environment has inherent safety implications that require consideration. To date, comprehensive safety testing of intracranial electrodes has not been performed at high field strengths. We therefore address this issue using a phantom model as a necessary prerequisite for future intracranial EEG-MRI studies.

Methods

Ex vitro measurements of electrode movement were assessed using the *Deflection Angle Method* [1] and the *Torque Rating Method* [2]. Induced voltage and temperature measurements were performed *in vitro* using a phantom constructed to model the shape, size, and conductivity of the human head. The phantom consisted of a saline-gel 'brain' surrounded by 0.9% NaCl saline fluid held in a custom hollow plastic sphere. An intracranial electrode grid (Ad Tech, Racine, WI) was secured on the 'brain' surface in an orientation typical of actual intracranial implantation. The electrodes were connected via shielded cable to a digital oscilloscope (Tektronix Inc) and induced voltage measurements (0 MHz – 200 MHz) were taken across electrode pairs (one active, one ground). Fiber-optic temperature probes (Fiso Technologies Inc, Montreal, QC) were used to monitor electrode, air and phantom reference temperatures (+/- 0.1 ˚C accuracy). Measurements were taken were taken within the static 3 Tesla MR environment (Signa; GE Healthcare, Waukesha, WI) and during typical clinical and research MRI protocols. Scans were performed with radiofrequency (RF) transmitter and magnetic gradients (GR) independently switched on to investigate the effects of their respective fields. Measurements were taken during diffusion-weighted (DWI), fluid attenuation inversion recovery (FLAIR), fMRI (*i.e.*, gradient-echo T2*-weighted), and T1-weighted MRI.

Results

The intracranial electrodes experienced no measurable displacement forces or torque in the MR environment (static or during imaging). Induced voltages ranged from 50 mV to 100 mV due to gradient switching, 800 mV to 3500 mV for both RF only and RF/GR combined (Figure 1). Induced voltages oscillated at low frequencies (< 100 kHz) due to gradient switching and at 127 MHz (corresponding to the Larmor frequency at 3 Tesla) for RF and RF/GR combined. Temperature changes along the electrodes deviated from air and surrounding tissue temperature by less than 0.1 ˚C over a 90 minute scanning period (Figure 2).

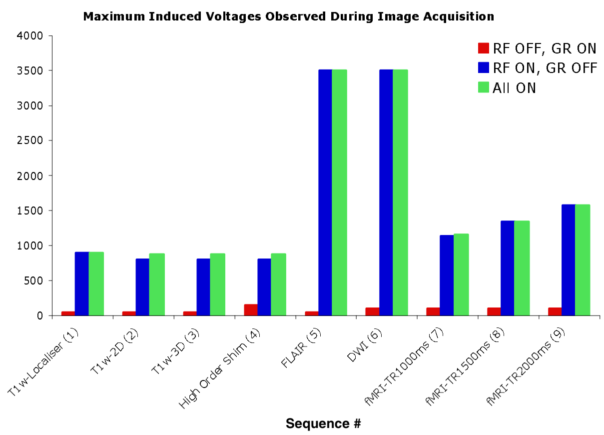

Figure 1. Induced Voltage Results.

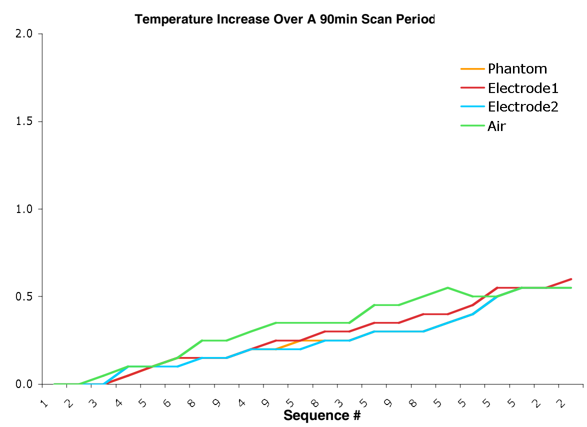

Figure 2. Temperature Results.

Conclusions

These preliminary results indicate that deflection, torque and temperature effects are within safety limits (deflection angle << 45˚, torque = 0 and < 4 ℃, respectively). The induced voltage due to gradient switching contributes very little to the total line voltage and is not of sufficient amplitude to result in neuronal stimulation. The amplitude of induced voltage due to the RF field is within the range to induce neuronal responses; however, the frequency is significantly higher than the < 10 kHz range required to produce neuronal activation. These results suggest that intracranial EEG-MRI should be safe at 3 Tesla.

References

1. American Society for Materials and Testing.
2. Shellock et al. *Magnetic Resonance Imaging* 2002; 16:721–732.