Safety and Feasibility of Using Implanted Depth Electrodes for Intracranial EEG-fMRI at 3 Tesla

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BACKGROUND

The increasing use of integrated scalp electroencephalography (EEG) – functional magnetic resonance imaging (fMRI) has expanded our understanding of the mechanisms underlying seizure generation in epilepsy and fueled further investigation into the electrophysiological changes that contribute to the condition. However, recording cortical electrical events from the scalp, at a distance from the current source, has significant limitations. Investigations involving simultaneous recording of intracranial EEG – fMRI are not limited in the same way electrographically, and hold great potential in the further elucidation of the mechanisms of seizure generation. Introducing implanted devices such as intracranial EEG depth electrodes in the MR environment holds inherent safety issues that require consideration. To date, no known comprehensive safety testing has been conducted to examine the feasibility of performing intracranial EEG-fMRI using depth electrodes at high field strengths. We therefore address this issue by examining the safety of depth electrodes using a phantom head model as a necessary prerequisite for future intracranial EEG-fMRI studies in humans.

METHODS

A phantom model was constructed to emulate the shape, size and conductivity of the human head (Figure 1), in which an intracranial depth electrode (Ad Tech, Racine, WI) was implanted. Measurements were obtained from the implanted device to examine movement, temperature and induced current through a series of MR scanning conditions. Device movement was measured in a standard head coil using two separate methods to determine both translational and rotational forces. Temperature measurements were obtained from two locations on the depth electrode, a reference location within the phantom, and in the air external to the phantom. Temperature was monitored and recorded consistently over each scanning session using a four-channel, fibre-optic thermometry system (Fiso Technologies, Montreal, QC). Induced voltages during scanning, and voltage frequencies were measured using a digital oscilloscope (Tektronix, Wilsonville, OR), and for a variety of phantom and probe positions. In addition, current was measured using a commercial EEG-fMRI system (Synamp, Compumedics Neuroscan, El Paso, TX), while an external signal generator provided a regular frequency sinusoid. All measurements were performed at 3 Tesla using a GE Signa scanner under the following MR scanning conditions: T_1-weighted 3-plane localizer, 2D anatomical, T_1-weighted 3D anatomical, high-order shimming, fluid attenuation inversion recovery (FLAIR), gradient-recalled echo planar imaging (GRE-EPI) and T_2*-weighted GRE-EPI fMRI (explored with TR of 1000ms, 1500ms, and 2000ms).

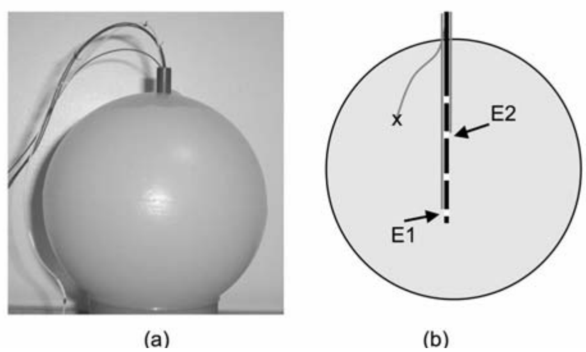

Figure 1: Phantom for *in vitro* testing (a) Shape: spherical; Diameter: ~12cm; Conductivity: ~0.7S/m (at 3 Tesla, ie., 127MHz). (b) Temperature probe locations: Electrode positions E1 and E2; Phantom reference point 9marked 'x').

RESULTS

The intracranial depth electrodes experienced no measurable rotational or translational deflections throughout the entire scanning period, except a 2° change due to table movement as it advanced into the scanner bore. Temperature changes from depth electrodes and surrounding phantom tissue were less than 0.5°C throughout all scanning conditions. All induced voltages oscillated at the Larmor frequency of ~127MHz, and ranged from 200-2800mV depending on the scanning conditions (induced voltages were greatest for FLAIR and DWI/DTI, then fMRI sequences and lowest for T_1-weighted anatomical images and high order shim sequences). Induced voltages using the depth electrode with commercial EEG-fMRI system oscillated at 60kHz or ~120kHz with a peak voltage of 450-650mV.

CONCLUSION

Our investigations of the safety of intracranial depth electrodes at 3 Tesla are promising. Temperature changes were well below a conservative safety limit of 4°C, and deflection of the device in the MR environment was undetectable. The amplitude of induced voltage was within the physiologically active range; however, the frequency is several orders of magnitude higher than the <10kHz necessary to produce inadvertent neuronal stimulation. These results suggest that intracranial depth electrodes should not pose a risk in performing intracranial EEG-fMRI at 3 Tesla.