Safety of localising intracranial EEG electrodes using MRI

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Background: MRI is attractive for post-surgical localisation of intracranial EEG electrodes in epilepsy patients as it allows good visualisation of the implant position in relation to neuroanatomy. However, the possibility of injurious RF induced heating around 'elongated' conductive implants is a concern[1-4]. While some electrodes are listed as 'MRI compatible'[2,3] there are no comprehensive safety studies in the literature. Implantation procedures commonly involve a combination of electrodes of different types (subdural grid/strip/depth), which can interact, and potentially increase RF induced heating. Strip and grid electrodes have a set of disk shaped electrode contacts that record electrical signals from the cortical surface, grid electrodes are simply a set of strip electrodes joined together to record EEG from a larger area. Depth electrodes are small diameter rods with cylindrical contacts that penetrate brain tissue and can record from deep brain structures. We investigated MRI induced heating in a realistic test phantom containing a combination of depth, grid and strip electrodes aiming to closely replicate a surgical implantation. We also tested the effects of electrical contact between the various electrode tails (external leads) and the effects of bilateral depth electrodes coming into contact within the tissue.

Methods: A phantom was formed from Perspex in a shape and dimensions approximating those of an adult human torso[1] (Fig. 1), filled to a depth of 10cm with a semi-liquid gel formed from distilled water, poly-acrylic acid partial sodium salt (Aldrich Chemical) (8g/litre) and sodium chloride (0.70 g/litre) with electrical and thermal characteristics similar to those of human tissue[5]. Three depth electrodes were inserted perpendicularly to the sagittal plane, two on the left side and one on the right side (modelling implants targeting the left hippocampus and amygdala with contra-lateral control), plus a subdural grid and strip electrode (Ad Tech, Racine, WI) (modelling implants recording from the cortical surface). Two configurations were tested for the depth electrodes; 1) standard, with spatial separation between end contacts, avoiding direct electrical contact; 2) with electrical contact between the depth electrode end contacts. Both configurations were tested with a) all electrode tails bundled together and in electrical contact, and b) the electrode tails insulated and separated from each other.

Temperature measurements were made simultaneously from 4 positions using an MRI-compatible fluoroptic thermometer (Model 3100, Luxtron Corporation, Santa Clara, CA, USA; accuracy ±0.1ºC) at a rate of 0.5Hz. The sensors were sited at various positions on the electrodes including the depth and strip electrode end contacts and the corners of the subdural grid[5]. MRI was performed using a 1.5T GE Signa (GE, Wisconsin, USA) system with the standard transmit/receive birdcage head coil. A high-SAR (2.41 W/kg) 6 minute duration fast spin-echo (FSE) sequence was used to elicit the highest temperature changes likely in a structural imaging study.

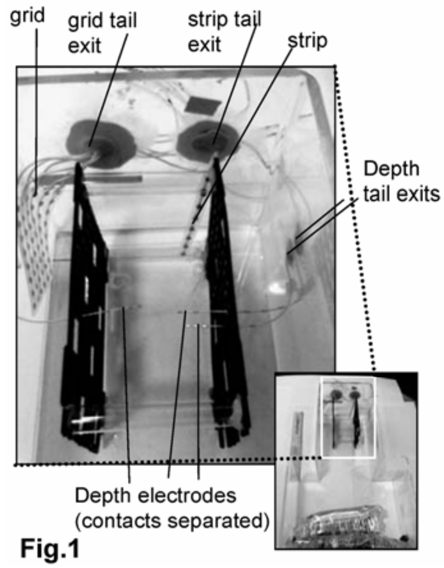

Fig.1

Electrode type	Tail arrangement	Max ΔT (ºC) (+/- 0.1)
grid	a) contact	1.7
	b) no contact	0.7
1) depth	a) contact	1.8
	b) no contact	<0.1
strip	a) contact	1.3
	b) no contact	0.2
2) depths touching	a) contact	1.9
	b) no contact	<0.1

Table Maximum temperature changes

Results: Maximum observed temperature changes (ΔTs) are summarised in the Table, with an example time course of ΔT plotted in Fig. 2. The main findings were: With the electrode tails separated the maximum ΔT was always <1ºC. Maximum ΔT was always increased by shorting the electrode tails. Both depth and grid electrodes showed a temperature change of nearly 2ºC with the tails shorted. The difference in maximum ΔT between the 2 electrode tail configurations was smallest for the grid electrode. Similar results were obtained for the two configurations of the depth electrodes.

Discussion: Current international guidelines[6] recommend that MRI-induced heating should not cause temperature in the head to exceed 38ºC, implying an allowable increase of <1ºC. With the tails separated we did not observe heating above this level suggesting that MRI is safe with the arrangement tested (GE 1.5T and a head transmit / receive coil). The SAR of the FSE sequence was high and the its duration 6 minutes; a higher SAR or longer duration sequence may cause a greater ΔT or conversely shorter or lower SAR sequences will reduce ΔT. Importantly, since the brain is additionally cooled by perfusion[7] the gel phantom used here is a conservative model for tissue heating. When the electrodes tails are connected together moderate heating occurs beyond the guidelines hence this should be avoided. Shorting the electrode tails had the smallest effect on ΔT for the subdural grid (which is equivalent to 6 adjacent strip electrodes). This suggests that there is already significant RF coupling between the grid electrodes. Further work will extend these results to 3T and whole body RF transmit coils.

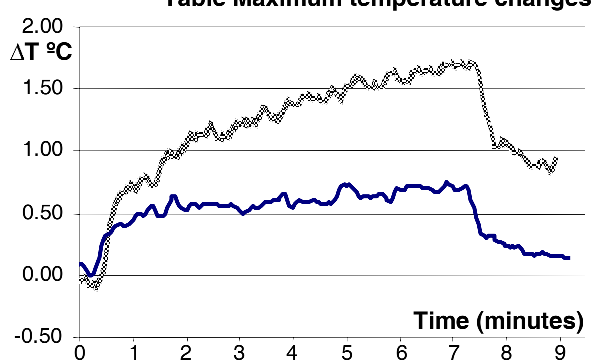

Fig. 2 ΔT from subdural grid electrode with (grey line) and without (dark solid line) the tails shorted

Conclusions: Shorting the electrode tails had a large effect on ΔT while shorting the depth electrodes within the gel did not. We observed a significant temperature increase in the phantom in contradistinction with a previous report[8]. This difference could be attributed to differences in the phantom, field strength, or pulse sequences used. Our results indicate that MRI in patients with these specific implants is safe in terms of RF heating at 1.5T using a head transmit/receive coil provided the electrode tails are separated and electrically insulated.

1. *Rezai AR, et al*, JMRI 15:241-250; 2002 **2.** *Zhang J* et al, Am J Neuroradiology 14:497-500, 1993. **3.** *Shellock FG*, 2005. Reference Manual for Magnetic Resonance Safety, Implants, and Devices: 2004. **4.** *Pictet et al*, Physics in Medicine and Biology; 47(16):2973-85, 2002. **5.** *Park SM et al*, IEEE transactions on magnetics 39 (5): 3367-3371, 2003. **6.** *IEC* 60601-2-33, 1995 revised 2002. **7.** *Salcman M et al*, J Neurosurg. Apr;70(4):592-8, 1989. **8.** *Boucousis SM et al*, Proc ISMRM 2006; 2055.