Safety of localising intracranial EEG electrodes using MRI: A comparison between head and body coils at 3T

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Background MRI is useful for post-implantation localisation of intracranial electro-encephalograph (EEG) electrodes in epilepsy patients providing good visualisation of implant positions in relation to neuroanatomy with no ionising radiation dose. However, the possibility of injurious RF induced heating around 'elongated' conductive implants is a significant concern[1-3]. While some intracranial electrodes designed for use in epilepsy monitoring are listed as 'MRI safe'[2-4], to our knowledge no systematic experimental investigation of the thermal safety of MRI with multiple intracranial EEG electrodes has been published. Implantation procedures commonly involve a combination of different electrode types (subdural grid/strip/depth), which can potentially interact electrically increasing RF heating. We investigated MRI induced heating at 3T in a tissue-simulating test object containing depth, grid and strip electrodes aiming to replicate a typical clinical configuration involving a large number of implants, and compared the effects of body and head coil RF excitation.

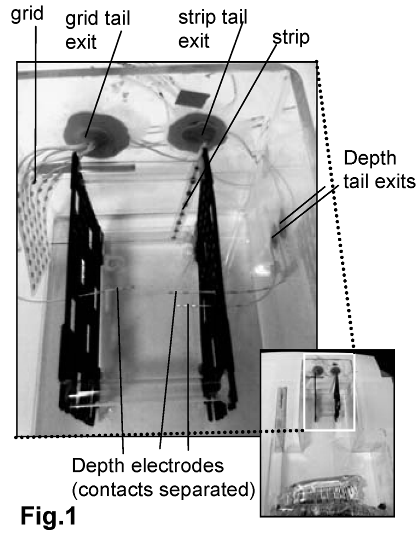

Fig.1

Methods A Perspex phantom with shape and dimensions approximating those of an adult human torso[1] (figure 1) was filled to a 10cm depth with a gel formed from distilled water, poly-acrylic acid partial sodium salt (Aldrich Chemical) and sodium chloride (8g/litre and 0.70 g/litre respectively) with electrical and thermal characteristics similar to those of human tissue[5]. Three depth electrodes (Ad Tech, Racine, WI) were inserted perpendicularly to the sagittal plane, 2 on the left side and 1 on the right side (modelling implants targeting the hippocampus and amygdale with contra-lateral control), plus a subdural grid and strip electrode (modelling implants recording from the cortical surface). MRI was performed firstly using a 3T Tim Trio system (Siemens Medical), using 2 RF coil arrangements: 1) standard head birdcage coil (USA instruments) for transmission and reception; 2) body coil transmit with the bottom half (6 elements) of a 12 channel head coil for RF reception. Further experiments were performed on a 3T Excite system (GE Healthcare) with a head transmit coil. In each case, measurements were performed with 2 distinct electrode external lead (tail) arrangements a) physically separated so that the terminations were an 'open circuit', as per the manufacturer's recommendation, simulating a 'standard condition', and b) bundled together so that the terminations formed a short circuit simulating a 'fault condition'. A high-SAR 6 minute duration fast spin-echo (FSE) sequence was used on both scanners to elicit the highest temperature changes likely in a structural imaging study and corresponding to the duration used for the IEC head-average SAR limit[6]. Temperatures were measured using an MRI-compatible fluoroptic thermometer (Model 3100, Luxtron Corporation, Santa Clara, CA, USA) at 4 positions: the distal tip (contact #1) and middle (contact #4) of the 8-contact depth electrode on the LHS, the corner of the grid (contact #48) and at a reference position within the neck region of the phantom away from all electrodes.

Table 1 Max temperature changes		ΔT°C Depth	ΔT°C Grid	SAR (W/Kg) head/body
Siemens 3T Head coil	a) short circuit	1.6	1.6	2.3/0.2
	b) open circuit	0.4	0.9	
Siemens 3T Body coil	a) short circuit	0.5	0.5	1.2/0.5
	b) open circuit	0.7	6.4	
GE 3T Head coil	a) short circuit	0.4	4.0	2.5/0.2
	b) open circuit	0.3	1.8	

Results Maximum temperature increases (ΔTs) are given in table 1, with maximum ΔT time course plotted in figure 2 for the Siemens Trio. The main findings were: 1) For the head coils; with the electrode tails separated the maximum ΔT was always <2ºC and was lower on the Siemens Trio. Maximum ΔT was always increased by short-circuiting the electrode tails. 2) For the body coil; much larger temperature increases (+6.4ºC) were obtained for the same imaging sequence (despite lower reported SAR values for this coil). In contradistinction to the head coil, the greatest ΔTs were elicited when the electrode tails were separated.

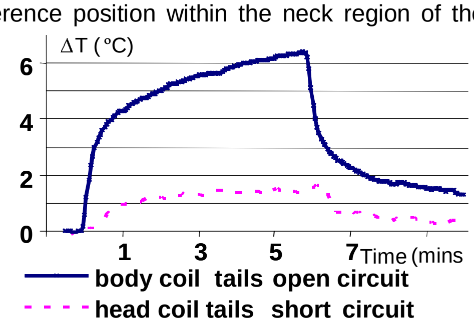

Fig. 2 Max electrode ΔT with different transmit coils (Siemens Tim Trio)

Discussion Current guidelines[6] recommend that MRI-induced heating should not cause temperature in the head to exceed 38ºC, implying an allowable increase of <1ºC. *For the head coil,* on both systems ΔTs were modest (<2ºC) under standard conditions; the use of MRI sequences with substantially lower SAR is clinically feasible, and would reduce ΔTs to within safe limits. However, the risk of excessive heating due to unforeseen experimental circumstances remains, emphasising the importance of rigorous compliance with locally-determined SAR limits, and maintaining electrode tail separation. *For the body coil,* ΔTs were considerably higher than for the same sequence with the head coil. This occurred under standard conditions with, in fact, less heating in the fault condition. This suggests that when the entire length of the electrodes (including tails) lies within the RF field, as occurs when using the body coil, interactions resulting in greater heating occur, likely due to an increased effective loop area exposed to the RF field. Body-coil RF transmission presents a significant injury risk and is not advised. *In conclusion,* MRI in patients with these specific implants can be performed safely in terms of RF heating at 3T, providing that external leads are separated, a head coil is used and SAR limited. General guidelines for SAR are difficult to devise due to inter-scanner variability in calculation methods[7] hence local safety assessments are essential.

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.** Kanal E, et al, Radiology. 1999 Jun;211(3):886-8. **5.** Park SM et al, IEEE transactions on magnetics 39 (5): 3367-3371, 2003. **6.** IEC 60601-2-33, 1995 revised 2002. **7.** Baker KB, et al, 2004, J Magn Reson Imaging 20:315–320.