EEG measurements at 7 Tesla using the Ink Cap

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INTRODUCTION In the few past years there has been an increase in the number of concurrent EEG and fMRI measurements [1][2] and a shift towards higher $\mathbf{B_0}$ fields. Safety issues at 1.5 Tesla were relatively a minor problem [3]. However, previous studies have shown that in certain extreme cases such as: (a) *very high magnetic fields* and/or (b) *large number of EEG electrodes*, safety may be an issue [4]. In order to address these challenges, we developed a disposable high resistive-lead EEG cap (*Ink Cap*^{TM}) to reduce Specific Absorption Rate (SAR) exposure and to preserve the original high image quality of the MRI system.

METHODS The *Ink Cap* (Figure 1) was made of blended microstrips measuring approximately 750 μm (width) by 125 μm (thick). The microstrips' resistivity was 2 kΩ/m and their length varied between 35 and 56 cm. The electrodes were Ag/AgCl rings.

We have validated the *Ink Cap* in three different ways: a) FDTD Simulations, b) Temperature measurements, and c) MR imaging (RF mapping, structural and functional imaging SNR measurements).

Figure 1: *The proposed Ink Cap.*

FDTD Simulations: The resistivity of the cap's microstrips was chosen in accordance with simulation results on a high-resolution (1×1×1mm^3) 29-tissue human head model. The XFDTD program (REMCOM Co., State College, PA, USA - based on the FDTD algorithm [4]) was used to estimate the electric and magnetic fields and SAR for different resistivities of the microstrip. All simulations were performed at the RF frequency of 300MHz corresponding to a $\mathbf{B_0}$ of 7T, and with an input power into the 16-element birdcage coil of 1W.

Temperature: We made temperature measurements using a Siemens Allegra 3T head-only system and a custom made 7T whole body system retrofitted with a Siemens console. We performed measurements on a 14 cm diameter solid stand-alone single tissue phantom (1.8 litres of H_2O, 42 gr. of Agarose composite hydrogel and 3.6 gr of NaCl) using: (a) the *Ink Cap*, (b) standard low resistive disc electrodes (Gold GRASS F-E5GH, resistivity 0.66 Ω/m), and (c) no electrodes. All temperature measurements were performed using a Luxtron 3100 Fluoroptic Thermometer (Santa Clara, CA, USA) with two MRI compatible sensor probes. The temperature values were recorded from the instrument via a serial port to a laptop. One probe was placed at about 7cm inside the phantom and the other one at about 4mm inside the surface. We reported measurements on the electrode with the highest temperature increase using a high-power T2-weighted turbo spin-echo sequence at 3T (T2-TSE sequence for 20 minutes, 0.1W/kg Whole body SAR)) and at 7T (T2-TSE sequence, 0.4W/kg Whole body SAR for 15 min). This power was much higher than the one used in a clinical study at 1.5T [3].

MR Imaging: We used an 18 cm diameter homogenous spherical phantom and applied the following sequences: (**a**) 2D spin echo with a single echo resulting in RF field maps, using TE=17ms; FA=720°; TR=300ms; FOV=300x300 mm^2; matrix=256x256 (**b**) Structural MPRAGE using TE=3.42ms; FA=7°; TR=2350ms; FOV=276x276 mm^2; matrix=256x256; and (**c**) Single shot gradient-echo EPI using TE=30ms; FA=90°; TR=3510ms; FOV=211x211 mm^2; matrix=64x64. Most of the preliminary MRI image quality studies were done at 3T, given the higher distortions and image warping present at 7 T.

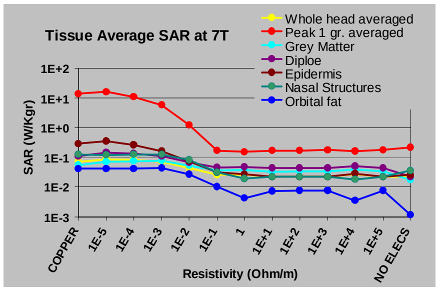

Figure 2: *Whole head, peak 1 gr and tissue average SAR on a 29-tissue head model for various resistivity values of the cap's microstrip in a log-log scale.*

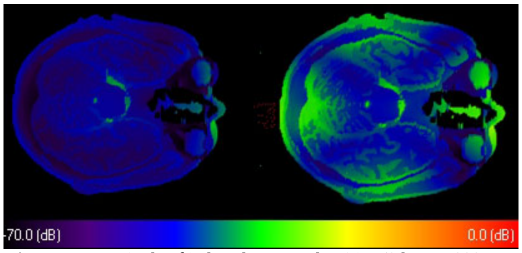

Figure 3: *Magnitude of induced current densities (0dB = 1,000 A/m^2) computed with the high-resolution head model for different values of microstrips resistivities: 1e^{+3} Ω/m (left) and 1e^{-3} Ω/m (right).*

RESULTS Figure 2 shows, for a wide range of microstip resistivity, whole head averaged and peak 1 gr. averaged SAR and averaged SAR values for several head tissues. We considered only the top five tissues that exhibited the largest SAR increases. We observe that resistivities higher than 0.1 Ω/m correspond to smallest averaged SAR values. The resistivity of the microstrip affects the induced currents (Figure 3) in the subject's head with hot spots that extend into the eyes. The resistivity value chosen for the *Ink Cap* (2 kΩ/m) was ***four*** orders of magnitude larger than this threshold value of 0.1 Ω/m.

Figure 4 shows the temperature measurement results at 7T. The temperature change (MRI^{off} – MRI^{on}) of the phantom near the electrode in PO7 (see the 10-20 standard montage) was three (3) times larger using the standard gold electrodes compared to the *Ink Cap*. In a similar experiment done at 3T, the temperature peak after 20 minutes was 2.4 °C in the standard electrode set and 0.8 °C in the *Ink Cap*. Figure 5 shows that the RF field maps ($\mathbf{B_1}$ field) distortions were negligible for the case of the *Ink Cap*. Additionally, the SNR comparison of the EPI images showed higher SNR when using the *Ink Cap* as a replacement for the standard gold EEG electrode set.

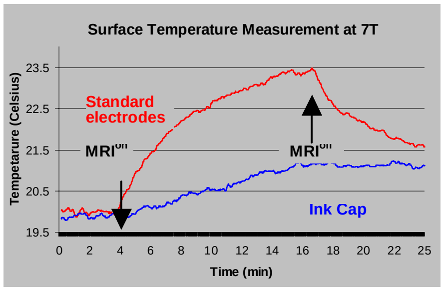

Figure 4: *Temperature measurement in the surface (PO7) of the agarose gel phantom, during a high SAR T2-TSE 20 min. sequence at 7T.*

CONCLUSIONS We designed a high-resistive 32 electrode EEG cap based on conductive ink technology, that employs inexpensive and disposable materials, tested for safety with $\mathbf{B_0}$ fields up to 7T. Simulations guided the design of this high resistive cap by studying the resistivity effects on the averaged SAR. The temperature increases observed were much smaller when using this cap compared to the standard electrode set, both at 3T and 7T. At the same time, the use of the *Ink Cap* seems to preserve the original MRI image quality. Results of this study show that the *Ink Cap* may improve subject's safety in *very high magnetic field recordings*.

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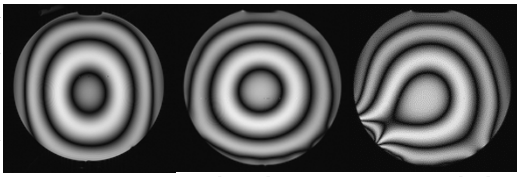

(a): No electrodes (b): *Ink Cap* (c): Standard electrodes

Figure 4: *RF field map images of the spherical phantom for different cases, at 3T.*

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