RF Safety at 9.4T - Porcine In vivo Results

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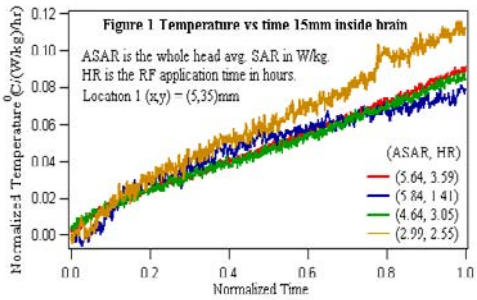
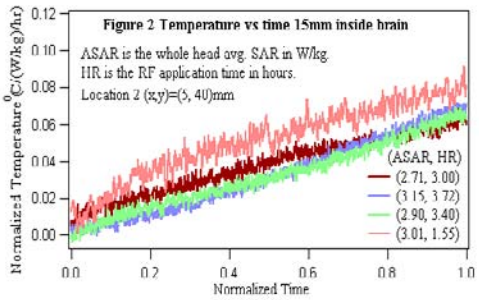
Introduction RF heating is a potential safety concern for ultra high field MRI applications. However, temperature is not monitored for safety assurance in MR exams. Temperatures exceeding FDA guidelines may be non uniform in anatomy, and difficult to measure by non-invasive means. The objective of this study was to correlate easily measured whole head average specific absorption rate (ASAR) to temperatures directly measured in porcine heads In vivo, in order to gain better understanding of RF heating and possibly a priori information for safety assurance in human studies. In this investigation, RF heating at 400 MHz (9.4T) was measured directly as a function of RF power, coil, and time in anesthetized porcine heads. By so doing, maximum temperatures could be predicted for a given ASAR, scan time and head coil.

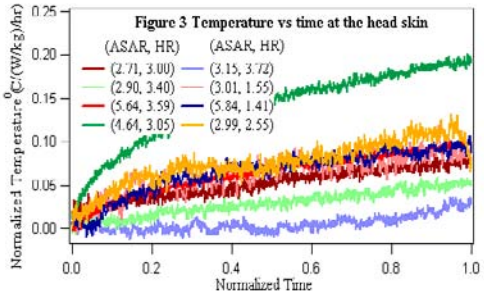
Experiment design and Methods

Temperatures were measured as a function of time in the brain and surrounding cutaneous layer of twelve human sized, anesthetized swine (mean animal weight=52kg, SD=±6.7kg). Pigs were chosen for this study because of their human comparable mass, perfusion, thermal properties, and thermo-regulatory reflexes as well as cost and availability. Continuous wave RF energy was deposited in porcine head using a four loop RF head coil at 400 MHz (9.4T). Temperatures were recorded continuously using an inline fluroptic probe placed at predetermined locations (3 transducers 5mm apart) inside the brain and a separate fluroptic probe in the cutaneous layer. To separate RF heating from anesthetic cooling, control temperatures were recorded in four anesthetized, but unheated swine (mean animal weight=49.8kg, SD=±9.1kg), in the brain and in the surrounding cutaneous layer for the duration of a heating experiment (~8hours). To study the RF heating contours the inline temperature probe was placed at two locations (N = 4 for each location). The number of animals was chosen as N=4 for each group. A minimum of N=4 animals was required for each group to have >90% power with P<0.05 (two-sided). The probe was inserted through an ~18 gauge hole drilled into the animal's cranium perpendicular to the coil plane such that the probe's three transducers were placed at 15, 10, and 5mm depths from the dura in the brain. A fourth probe was placed in the cutaneous layer. Temperature at all four probes was recorded continuously. Also monitored were the room temperature and humidity, and the animals' heart rate, blood pressure, end tidal CO_2, and the % inspired/expired anesthetic agent. The net average coil input power (forward minus reverse) was measured at the coil by a power meter (Giga-tronics Universal Power Meter, model #8652A). The animal experiment protocol was approved by the Institutional Animal Care and Usage Committee of the University of Minnesota.

Results and Discussion Figures 1 and 2 show the RF induced absolute temperature change normalized by the ASAR (W/kg) and the RF application time HR (hours) vs. time normalized by the HR at locations 1 and 2, respectively for four animals in each figure at a representative depth of 15mm inside brain. From the close curves in each of the figures it could be deduced that the normalized temperature change depended only on its location in the brain. Thus, it was possible to develop normalized In vivo, transient brain temperature maps for an RF coil at a given frequency and animal model (with approximately the same head size). These normalized temperature maps multiplied by the ASAR and time predict temperature change in the living tissue. The curves in figures 1 and 2 were easily explained since for a given frequency and approximately the same head size the relative power distribution was fixed. Thus, for a normalized RF heating time between 0-1, the RF coil caused a spatially unique normalized tissue temperature change if the effect of the local blood perfusion and the thermal diffusion was relatively unchanged. The RF induced temperature change in figures 1-2 was obtained by subtracting the extrapolated linearly decaying temperature of the animal obtained prior to the RF application from the actual temperature response of the animal after the RF was applied. This was valid since 1) temperature decayed linearly in our anesthetized, unheated porcine models, and 2) the slope of the linear temperature decay was unique to an animal (not shown here). Figure 3 shows the wide variability of the normalized temperature change in the cutaneous layer of the eight animals. Thus, it could be deduced that the normalized skin temperature change (and thus the absolute head skin temperature change) was not a reliable parameter to assess In vivo temperature change in 9.4T systems.







Conclusions Results showed that it was possible to develop normalized In vivo, transient brain temperature maps for an RF coil at a given frequency such that the normalized temperature maps when multiplied by the whole head average specific absorption rate (ASAR) and the RF heating time (HR) would predict In vivo temperature change during RF heating in swine. Further, it was shown that at 9.4 T 1) the RF heating caused a non uniform temperature distribution in the brain; and 2) the skin temperature change was an unreliable parameter to assess In vivo temperature change.

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References (1) CDRH, "Guidance for Industry and FDA Staff - Criteria for Significant Risk Investigations of Magnetic Resonance Diagnostic Devices", FDA, IEC-60601-2-33, 2003.