In Vivo Radio-Frequency Heating did not Change due to the Power Deposition from Similar 3T and 7T Head Coils

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Target Audience Researchers, Clinicians, MR Manufacturers, Regulatory Agencies

Introduction In vivo temperature responses were measured using fluoroptic probes in the scalp, brain, and rectum of eight swine due to a continuous wave (CW) power deposition with a 15 rung, 3T (Larmor frequency = 123.2 MHz, internal diameter or ID = 26.50 cm) and an 8 channel, 7T (Larmor frequency = 296 MHz, coil ID = 22.86 cm) TEM head coil of comparable IDs. The fluoroptic in vivo RF heating measurements were made to better understand the heating and identify safe thermal thresholds for adverse thermogenic responses at ultra-high fields. RF heating and its thermo-physiologic responses are not well understood at ultra-high fields (≥3T)[1]. Studying RF heating is important for human safety assurance since non-uniform RF energy distribution at ultra-high fields and blood flow may produce non-uniform in vivo temperatures (i.e., local hot spots)[2, 3]. The effect of non-uniform brain temperatures on the mammalian thermo-regulatory mechanisms is unknown.

Current international RF safety guidelines limit the maximum in vivo temperature change to 1 ^{0}C and the maximum whole head average SAR to 3 W/kg (averaged over any 6 minutes) in the human head[4]. However, MR systems monitor the SAR alone to assure safety since no non-invasive means are available to determine in vivo temperatures with the required accuracy and precision of less than 0.5 ^{0}C. Local distribution of RF power (local SAR) is routinely calculated in standard human geometries to design RF coils such that to meet allowable maximum local SAR guidelines. Cellular thermogenic hazards are related to in vivo temperatures and temperature-time history – not to the maximum whole head average and local SAR. 3 W/kg of the whole head average SAR when deposited for a 'long' duration may produce a temperature-over-time response in an imaged tissue to adversely affect the thermo-physiology of mammals. Thus, safety at ultra-high fields will be better assured by studying RF heating and its thermo-physiologic consequences in thermoregulatorily conservative, human relevant animal models at appropriate frequencies.

Experiment design and Methods The animal experiment protocol was approved by the Institutional Animal Care and Usage Committee of the University of Minnesota. In vivo temperatures were measured as a function of time in the sub-cutaneous layer of the scalp; 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm deep in the brain after the dura; and 10 cm deep in the rectum in eight anesthetized swine using fluoroptic probes (Coil = 3T, mean animal weight = 75.8 kg, SD = 5.6 kg; Coil = 7T, mean animal weight = 79.9 kg, SD = 7.8 kg) (N=4 for each coil). To measure the scalp skin temperature, an 18G catheter was used to place a fluoroptic probe in the sub-cutaneous layer of the scalp. To measure brain temperatures, an ~18G hole was drilled into the swine cranium perpendicular to the coil plane 45 mm away from the back of the skull and 5 mm lateral to the midline. Next, an 18G catheter was used to puncture the dura and the fluoroptic probes were slipped through the dura to appropriate depths. The pigs were kept anesthetized using 1.5-2.5% Isoflurane in 50% air – 50% O_2. The room temperature and humidity, and the animals' heart rate, blood pressure, respiratory rate, end tidal CO_2, and the % inspired/expired anesthetic agent were recorded manually every 30 minutes. A pig was chosen as a thermoregulatorily conservative model of a human for its human comparable mass, perfusion, electromagnetic and thermal properties, thermo-regulatory reflexes, and World Health Organization's recommendation. Swine have critical, hot temperature limit comparable to and lower than that of humans.

Continuous wave RF energy was deposited to swine with the head coils for three hours to produce the heating. Temperatures were recorded for ~3 hours before the RF exposure started (pre-RF epoch), for ~3 hours during the RF exposure (RF-epoch,), and for ~3-4 hours after the RF exposure stopped (post-RF epoch). The net average coil input power (forward- reverse) was measured at the coil by a power meter (Giga-tronics Universal Power Meter, model #8652A) (Coil = 3T, mean coil input power = 43.2 W, SD = 0.5 W; Coil = 7T, mean coil input power = 42.4 W, SD = 1.0 W). Comparable coil input power was provided to the coils to study coil-load coupling. The number of animals was chosen as N = 4 since a minimum of 4 animals was required for each group to have >90% power with P<0.05 (two-sided).

Results and Discussion Figures 1-2 present the RF power induced temperature changes due to the 3T head coil at 15 mm deep in the brain and 10 cm deep in the rectum, respectively. Figures 3-4 present the RF power induced changes due to the 7T head coil at 15 mm deep in the brain, and 10 cm deep in the rectum, respectively. No significant difference in heating was measured due to the two head coils in the brain and rectum suggesting that the effect of the frequency on the heating was minimal for these head coils and power levels. RF power induced temperature changes were unique in the brain and rectum suggesting that the effect of the head positioning and subject-to-subject variability on the RF heating was not significant for a given weight range and head coil. RF heating in the brain was significantly higher than in the rectum. Thus, rectal temperatures may not be used to gauge heating in the brain during head imaging. The temperatures kept increasing and no plateau (i.e., steady state) was achieved within 3 hours of the heating (Figures 1-4)[1-3]. Thus, power and imaging time should be minimized to minimize the heating.

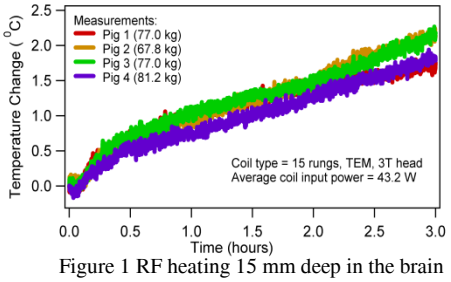

Figure 1 RF heating 15 mm deep in the brain after the dura due to a 15 rung, 3T head coil.

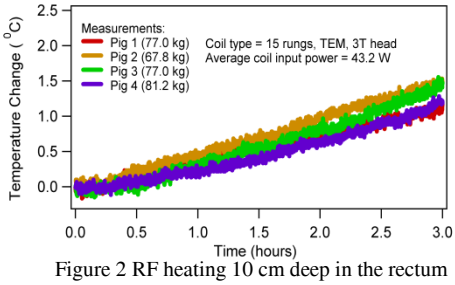

Figure 2 RF heating 10 cm deep in the rectum due to a 15 rung, 3T head coil.

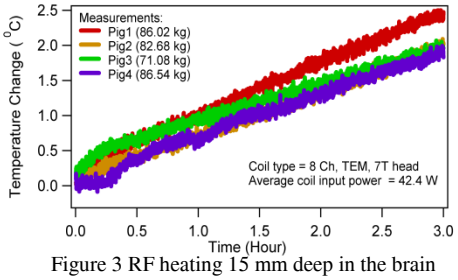

Figure 3 RF heating 15 mm deep in the brain after the dura due to an 8 channel, 7T head coil.

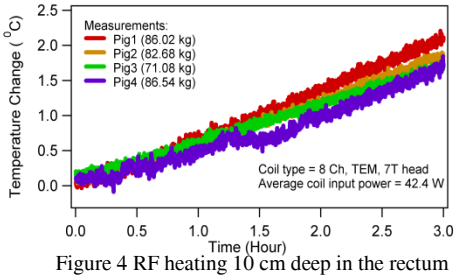

Figure 4 RF heating 10 cm deep in the rectum due to an 8 channel, 7T head coil.

Summary RF heating was insignificantly different due to the power deposition from similar 3T and 7T head coils in the brain and rectum. The RF power induced temperature changes were unique for a location. The RF power induced temperature changes did not plateau (i.e., steady state) within 3 hours of the heating.

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References 1) D. Shrivastava, T. Hanson, J. Kulesa, L. DelaBarre, P. Iaizzo and J. T. Vaughan, Magn Reson Med **62** (4), 888-895 (2009). 2) D. Shrivastava, T. Hanson, J. Kulesa, J. Tian, G. Adriany and J. T. Vaughan, Magn Reson Med **66** (1), 255-263 (2011). 3) D. Shrivastava, T. Hanson, R. Schlentz, W. Gallaghar, C. Snyder, L. Delabarre, S. Prakash, P. Iaizzo and J. T. Vaughan, Magn Reson Med **59** (1), 73-78 (2008). 4) IEC, International Electrotechnical Commission **60601-2-33-ed3.0b** (3rd Ed3.0b) (2010).