Radiofrequency Heating during Head Imaging in a 3T Transmit Body Coil

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Target Audience All MR personnel including MR manufacturers, Clinicians, Researchers, Patients, Human Research Subjects, and Regulatory Bodies.

Introduction In vivo radiofrequency (RF) heating during head imaging with a transmit body coil was simulated by solving the new, analytical generic bioheat transfer model (GBHTM) and the 'gold standard' empirical Pennes bioheat transfer equation (BHTE) in a digital pig (weight = 71.48 kg) with the pig head in the isocenter of a 3T, birdcage, transmit body coil. The simulations were validated by direct fluoroptic temperature measurements in five anesthetized swine. The simulations as well as the measurements were made since the RF heating during head imaging with a body transmit coil is unknown and a safety concern. Further, no validated thermal models are available to simulate such heating. Simulations were performed by solving the GBHTM since this was a newly derived bioheat model based on the conservation of energy[1]. Simulations were performed by solving the empirical Pennes BHTE since this was the 'gold standard' bioheat model that had been used in the past to predict heating as well as determine 'safe' limits for the local and global specific absorption rates (SAR) to keep in vivo temperatures below safe thresholds[2, 3].

Current international RF safety guidelines limit the maximum whole-head average SAR to 3.2 W/kg of head weight and whole body average SAR to 4 W/kg of body weight averaged over any six minutes of power deposition. Local SAR is limited to 20 W/kg per gram of tissue in the head and trunk, and 40 W/kg per gram of tissue in the extremities averaged over any six minutes of power deposition. The maximum whole-body average SAR of 4 W/kg can be delivered for up to 60 minutes. The guidelines expect that this amount of RF energy deposition will result in safe in vivo temperature changes (i.e., core temperature ≤ 1 ^{0}C and local temperature change ≤ 3 ^{0}C, assuming core body temperature of 37 ^{0}C), as simulated using the Pennes BHTE [3].

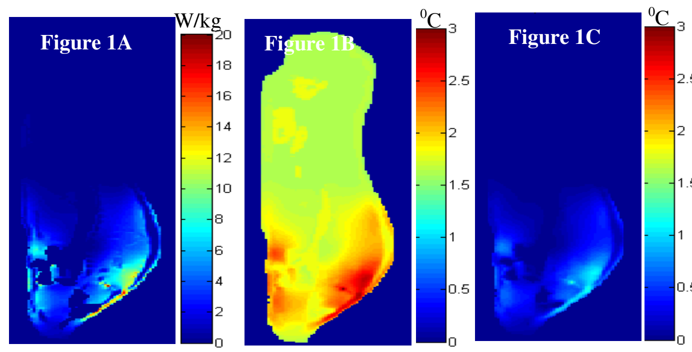
Methods – The Digital Pig Model A digital pig model was developed by acquiring 1.5 mm isotropic, whole-body anatomic images of a ~73.61 kg euthanized pig with computed tomography (CT). The images were segmented in six tissue types (i.e., skin, fat, muscle, bone, lungs, and internal air) using MIMICS software (Materialise, Belgium). Appropriate electromagnetic and thermal properties were assigned to the tissues. The digital pig had a mass of ~71.48 kg.

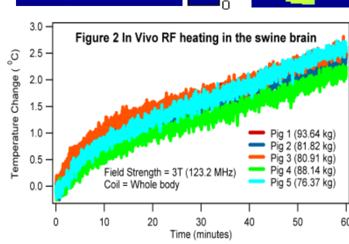
Methods – Simulations Local temperature changes were simulated by solving the GBHTM and Pennes BHTE. A 'C' script was written to implement the bioheat models. Necessary local SAR distribution was obtained by importing the digital pig in REMCOM finite difference time domain software (State College, Pennsylvania, USA) and solving Maxwells equations for the digital pig with its head in the isocenter of a 3T body coil. The 3T (~123.2 MHz) body coil was modeled as a 16 channel, high pass, 50 cm long, 60 cm internal diameter (ID) bird cage coil shielded with a 120 cm long and 65 cm ID faraday cage. The difference between the GBHTM and Pennes BHTE arises in the way these models treat blood temperature. The GBHTM allows blood temperature to vary spatially and temporally based on the conservation of energy. Pennes BHTE assumes blood temperature constant, which artificially maximizes blood-tissue heat transfer rate in deeper tissues.

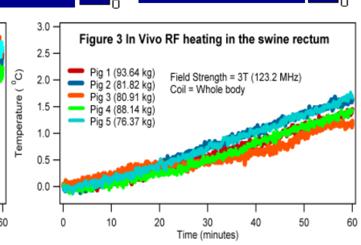
Methods – Experimental Design The animal experiment protocol was approved by the Institutional Animal Care and Usage Committee of the University of Minnesota. RF heating was measured as a function of time using fluoroptic probes in the sub-cutaneous layer of the scalp; 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm deep in the brain after the dura; 5 cm deep and 4.5 cm proximal from the end of the skull, 5 mm lateral to the midline (simulated hot spot); and 10 cm deep in the rectum. The measurements were made in five anesthetized swine (N= 5, mean animal weight = 84.03 kg, SD = 6.85 kg). Temperatures in the scalp were measured by placing a fluoroptic probe in the sub-cutaneous layer with an 18G catheter. 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. Temperature in the neck was measured by placing a fluoroptic probe at the appropriate depth using an 18G catheter. The pigs were kept anesthetized using 1.5-2.5% Isoflurane in 50% air – 50% O_2. The animals' 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.

The RF heating was produced in a clinical 3T scanner due to an hour long turbo spin echo (TSE) sequence (whole body average SAR = 2.65 W/kg, SD = 0.22 W/kg). Temperatures were recorded for ~1 hour before the RF exposure started, for ~1 hour during the RF exposure, and for 0.75 hour after the RF exposure stopped. The number of animals was chosen as N = 5 since a minimum of 4.0 animals was required to have >95% power with P<0.01 (two-sided).

Results and Discussion Figure 1A presents the local SAR distribution in the sagittal plane of the digital pig due to the RF power deposition from the 3T coil for the whole-body average SAR of 2.65 W/kg. Figures 1B and 1C present the associated local temperature change distribution at the end of the RF deposition simulated using the GBHTM and the Pennes model, respectively. Figures 2 and 3 present the local temperature change measured in the brain and rectum, respectively. Results show that the GBHTM simulated the measured RF heating more accurately. Pennes model underestimated the RF heating. The whole-body average SAR of 2.65 W/kg produced temperature changes of ~2.47 ^{0}C in the brain and 1.48 ^{0}C in the rectum at the end of an hour long RF heating. Rectal temperature change was significantly lower than the brain temperature change and should not be used to gauge heating in the brain.







Summary New measurements were made to estimate RF heating during head imaging with a 3T birdcage transmit body coil. The GBHTM simulated RF heating more accurately compared to Pennes BHTE. Approximately 1 ^{0}C temperature change was simulated using the GBHTM and measured using fluoroptic probes in the brain due to the whole-body average SAR of 1 W/kg in 1 hour.

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