Development of an Anatomical Accurate Porcine Head Model to Study Radiofrequency Heating due to MRI

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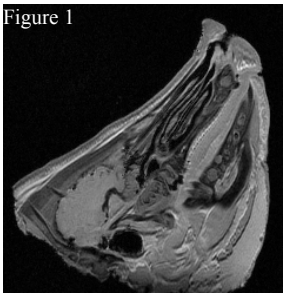
Introduction An anatomically accurate porcine head model was developed to study radio-frequency (RF) heating due to MRI. The head model will be used to help validate the temperature predictions of the newly derived bioheat equation the Generic Bioheat Transfer Model (GBHTM) against direct, in vivo fluoroptic temperature measurements (1). The validated GBHTM will be used to predict RF heating in swine and humans at high fields (i.e., static field strengths ≥ 1.5T) with and without conductive implantable medical devices (IMDs).

Current international RF safety guidelines limit the maximum in vivo temperature change to 1 ^{0}C, maximum whole head average SAR to 3 W/kg (averaged over any 6 minutes), and maximum 10 gm tissue average local SAR to 10 W/kg (averaged over any 6 minutes) in a human head (2). MR systems monitor the whole head average SAR alone to assure safety. Additionally, local distribution of RF power (local SAR) is routinely calculated using standard, non-perfused human geometries without IMDs. However, cellular thermogenic hazards are related to in vivo temperatures and temperature-time history – not to maximum whole head average or local SAR. RF heating depends on the field strength, geometry, tissue type, coil, blood flow, and the location of the IMD. RF heating and its effects on a mammalian thermo-physiology are not well characterized at high fields in tissues with and without IMDs. An anatomically accurate animal head model is required to validate bioheat equations to determine in vivo RF heating and study thermo-physiologic effects of non-homogeneous RF heating for a variety of field strength, coil types, geometries, and IMD positions.

Swine is a thermo-physiologically conservative animal model for humans. Swine have human comparable mass, perfusion, thermal properties, and thermo-regulatory reflexes. Additionally, swine are cheap and widely available. Swine are routinely used to study RF heating and its thermo-physiologic consequences at high fields (3,4). Thus, an anatomically accurate head model was developed using a swine head.

Experiment design and Methods A swine head was severed at the first cerebral vertebra C1. A high resolution image of the swine head (animal weight = 80 kg) was acquired at Siemens 3 T trio using a T1MPRAGE sequence and the following parameters: FOV = 260 mm X 260 mm, Slices = 192, Resolution = 1.02 mm X 1.02 mm, Slice Thickness = 1 mm, Flip Angle = 15 ^{0}, TR = 1380 ms, TE = 2.6 ms, TI = 800 ms (Figure 1). The obtained DICOM image was imported in MIMICS (Materialise, Ann Arbor, MI 48103). The image was segmented into brain, cerebral spinal fluid (CSF), bone, cartilage, muscle, and air cavity using pixel intensities and various other inbuilt tools in MIMICS. MIMICS was used since along with providing segmented tissues the software provided automated, quality, finite element meshes of the segmented tissue types. Meshed tissue regions can be directly imported in commercial finite element and finite volume softwares (e.g., ANSYS, FLUENT, COMSOL, etc.) to model RF heating using the GBHTM and other bioheat equations.

Figure 1



Results and Discussion A porcine head was segmented in five regions (i.e., brain, CSF, bone, cartilage, muscle, and air cavity) (Figure 2). Regions were meshed using eight nodded hexahedral elements in MIMICS and imported in commercially available finite element software ANSYS for RF heating studies (Figure 3). Readily segmenting relevant tissue types from high resolution MRI images using commercial softwares and determine RF heating using the validated GBHTM will better assure RF safety at high fields by opening doors to subject specific RF heating modeling.

Figure 2A Brain | Figure 2B CSF | Figure 2C Bone | Figure 2D Cartilage | Figure 2E Muscle | Figure 2F Air Cavity

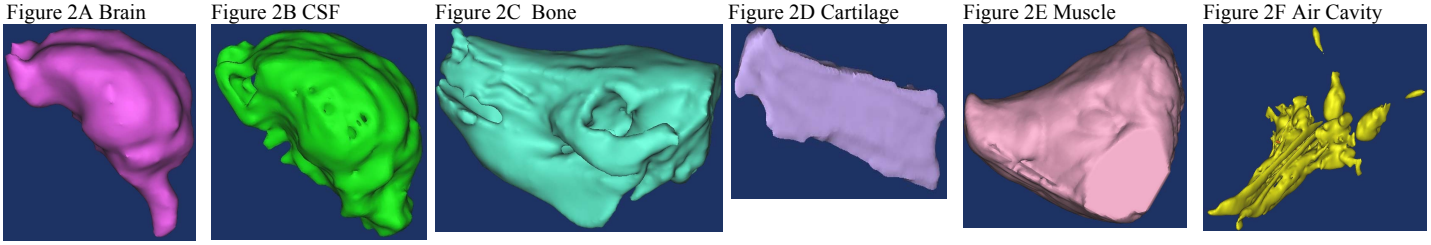
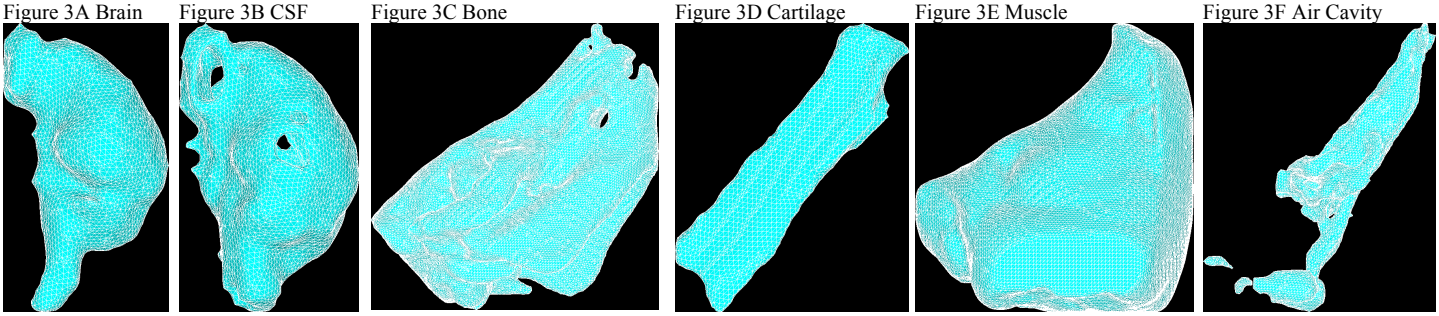


Figure 3A Brain | Figure 3B CSF | Figure 3C Bone | Figure 3D Cartilage | Figure 3E Muscle | Figure 3F Air Cavity



Summary An anatomically accurate porcine head model was developed to study RF heating due to MRI. Future studies to validate the predictions of the new bioheat equation the GBHTM are underway using the anatomically accurate porcine head model and previously obtained direct fluoroptic temperature measurements.

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References 1) Shrivastava et al., J Biomech Eng – T ASME 2009, 131(7):074506. 2) ICNIRP, Health Phy, 2004, 87(2):197-216. 3) Shrivastava et al., MRM 2008, 59(1):73-78. 4) Shrivastava et al., MRM 2009,62(4):888-895.