# Use of a NURBS-Based, Full-Body Anatomy and FEA Model to Evaluate RF-Induced Heating during MR Imaging

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**Target Audience:** Researchers, engineers and regulatory scientists evaluating RF-induced heating during MR imaging.

**Purpose:** Computational methods to evaluate RF-induced heating during MR imaging have been traditionally based on predicting specific absorption rate (SAR) using finite-difference time-domain (FDTD) analysis. These methods have been widely used to predict SAR distributions in anatomic models reconstructed from CT, MR and cryosectioned images[1]. In FDTD analysis, the model is discretized with a voxelized representation and a large number of small voxels is required to capture detailed anatomic features thus making the analysis computationally expensive. The voxel representation also limits the ability to include implants with complex geometries without the need for submodeling. Lastly, the FDTD method does not lend itself easy to calculation of the temperature rise and the published data on this aspect is limited. A multiphysics-based finite element analysis (FEA) approach can incorporate geometric features with high fidelity at minimal computational expense and provide a coupled transient thermal solution[2]. The current work extends the FEA methodology with the use of a NURBS-based anatomical model developed from MR, CT and cryosectioned data. SAR predictions from the FEA model are compared to published data. This work has implications for predicting the effect of passive devices such as stents and orthopedic implants on the local SAR and temperature rise due to exposure to MRI fields.

**Methods:** In 2001, the Visible Korean Human (VKH) experiment[3] produced MR, CT and cryosectioned image data of a male cadaver. The current study built on the VKH data by importing the CT image data into the ScanIP software environment (Simpleware Ltd, Exeter UK) for image processing and segmentation of different anatomical domains (Figure 1 A and B). The +NURBS add on module was used to create Non-Uniform Rational B-Spline (NURBS) parametric models from each segmented domain in the IGES format (see Figures 1C and D). The finalized anatomical model has a mass of approximately 55 kg.

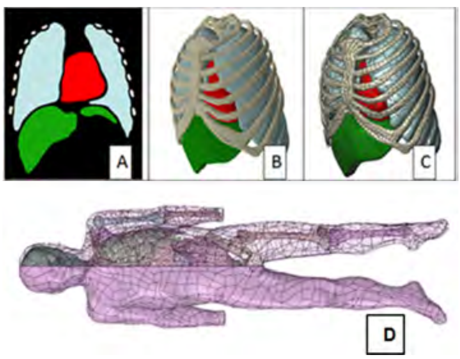


**Fig. 1: Example of use of Simpleware software to segment anatomical geometries [A - Bone (Cream), Lungs (Lt. Blue), Heart (Red), Liver (Green)] from 3D image data and to generate a cubic voxel model (B) then convert to NURBS surface geometry (C). Full-Body NURBS-based geometry (D) including: Body, Clavicle (l+r), Humerus (l+r), Radius (l+r), Ribcage (T1-T8 vertebrae with attached ribs and sternum and conjoining cartilage), Scapula (l+r), Skull, Ulna (l+r), Vertebrae (C1-C7, L1-L5, T9-T12 with the detached ribs), Femur (l+r), Hip (Pelvis and Sacrum), Patella (l+r), Tibia (l+r, with joined Fibula), Bladder, Brain, Heart, Intestines, Kidney (l+r), Liver, Lungs (l+r), Stomach.**

**FEA Model Development:** The NURBS surface geometry was imported into the commercial FE package COMSOL Multiphysics® for volumetric meshing and analysis. A shielded birdcage RF coil was developed to simulate operation of a 3T MRI and the coil was placed to expose the virtual anatomy at the knee location. Material properties for the individual organs and bones were taken from the IT'IS online database[4]. Average tissue properties were used for the remaining volume of the body cavities out to the skin boundary. The analysis model consisted of the anatomical phantom, birdcage coil and air domain. A steady state frequency domain solution of Maxwell's equations was obtained in the entire model and coupled to a transient thermal solution in the anatomical phantom. The RF coil was energized for a period of 900 s, followed by a cool-down of 300 s, in accordance with ASTM 2182-11a standard test method[6].

**Results:** SAR predictions from the current FEA simulation (Figure 2A) are compared with those from a published FDTD based simulation (Figure 2B)[5] . Good agreement is observed in both distribution and magnitude when comparing the FEA and the FDTD simulations despite the differences in anatomical detail. Increases in local SAR are observed in regions where the electrical properties change abruptly (i.e., from tissue to bone) as shown in Figure 2C. Figures 2D and 2E give temperature rise results and the maximum temperature occurs at a location away from the axis of the RF coil; this is consistent with previous simulation and experimental results seen in the ASTM standard phantom[6].

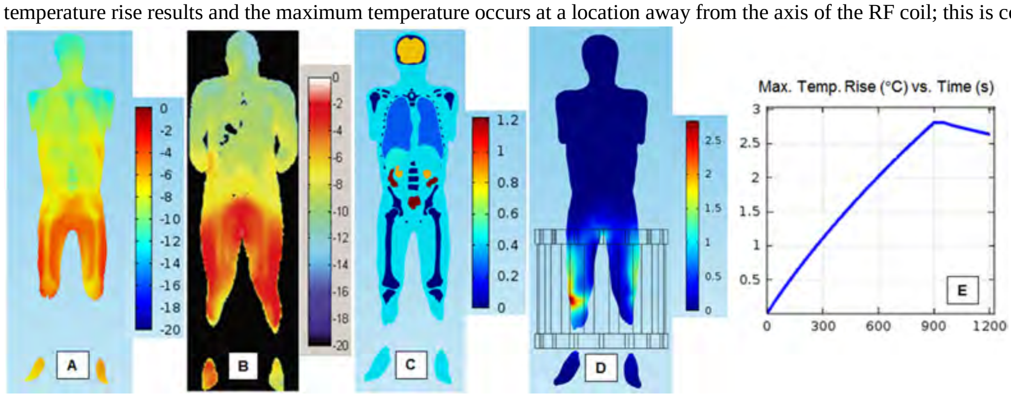


**Fig. 2: (A & B) Partial body SAR distributions averaged over 10 g spheres, log scale for coronal slice plane from 3T birdcage MRI coil at knee location for (A) current study solution developed using COMSOL Multiphysics® FEA and (B) visible Man FDTD solution by Wang 2012[5]. (C) Electrical conductivity (S/m). (D) Temp. rise (°C). (E) Maximum temperature rise (°C) vs. time (s).**

**Discussion:** The current work demonstrates the utility of FEA for predicting SAR and providing a direct measure of temperature rise induced by RF coils within the anatomy. Use of a NURBS-based anatomical model allows discretization of multiple anatomic structures and tissue types. Future work will focus on extending this approach to include the presence of passive devices with high geometric fidelity located in the anatomy and the resulting effect of exposure to electromagnetic fields produced by MRI coils.

**References:** [1] Yeo *et al.*, 2011, J. Mag Res. Imaging 33:1209-1217
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[3] Visible Korean Data Set (Park *et al.*, 2006, 2008; Dai *et al.*, 2012)
[4] IT'IS online property database (http://www.itis.ethz.ch/). Accessed May 2014.
[5] Wang, Z. *et al.* IEEE Antennas and Propagation Magazine, Vol. 54, No. 2, April 2012
[6] ASTM F2182-11a, Standard Test Method for Measurement of RF Induced Heating On or Near Passive Implants During Magnetic Resonance Imaging.