Comparative Analysis of Different Versions of a Human Model Located Inside a 1.5T MRI Whole Body RF Coil

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Introduction

Safety limits based on the specific absorption rate (SAR) in MRI as well as assessing in-vivo RF-induced heating for active implantable medical device leads are typically derived from numerical electromagnetic (EM) simulations of a set of human body models. Most available models are discretized voxel-based geometries that are generally simulated by EM time-domain solvers. In such a case, electrical contact between anatomically connected parts of tissues is not ensured; this may significantly influence the electromagnetic field generated inside a human body [1]. There is no consensus in requirements for the refinement level of human models used for the safety assessment of MRI coils and RF-induced heating on or near an implant.

The goals were: to analyze differences in the electromagnetic field generated in two different versions of Visible Human Project® (VHP)-Female models (i.e. v2.2 and v4) [2] with different refinements located at head and torso landmark positions in a 64 MHz whole body MRI coil.

Methods

The MRI coil utilized was a 64 MHz high pass 16 rung birdcage design with dimensions relevant to clinical 1.5 T scanners: a coil inner diameter of 604 mm and a coil length of 650 mm. The rings and rungs were made of copper strips (50 mm wide and 0.5 mm thick). The coil was shielded by a copper tube of 665 mm in inner diameter and 1520 mm in length. To mimic the clinical case, the fixed coil was tuned, matched and decoupled when loaded by a human multi-tissue model at the landmark position for torso MRI examination (Fig. 1a). The corresponding simulations of human models at the head landmark position (Fig. 1b) were done with values of fixed and variable capacitors obtained from the previous step. Our investigation was performed using RF circuit and 3-D EM co-simulation as described in detail in [3]. The RF circuit simulations were performed with ADS 2016 (Agilent, Santa Clara, CA, USA), and the 3D EM simulations with HFSS 2014 (ANSYS, Canonsburg, PA, USA). The 3D EM mesh adaptation procedure with 30% increase of mesh elements per step was stopped if the variation of ||***E***||max (maximum of electric field magnitude (||***E***||) over entire human model) between two consecutive meshes was less than 3%. ***E*** and ***H*** inside the human models were obtained on an equidistant mesh of 1 mm.

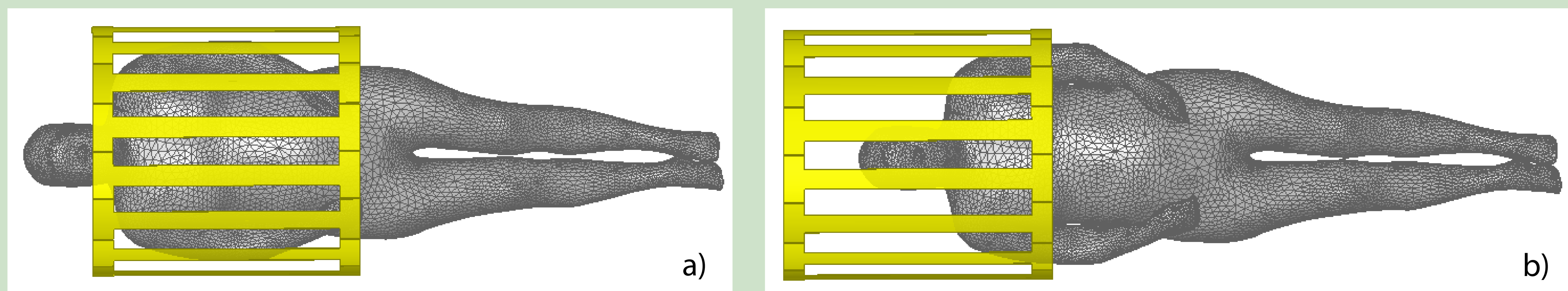


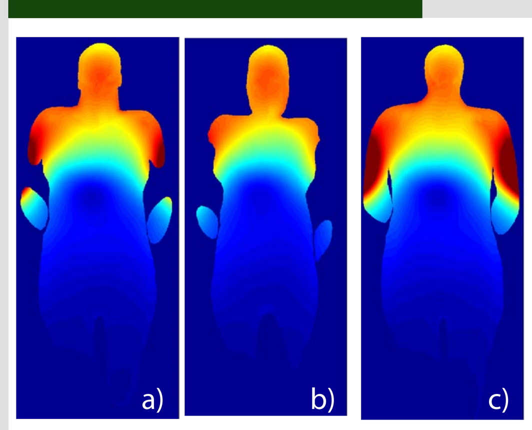
Figure 1. VHP-Female landmark positions in the birdcage coil: a) torso examination; b) head examination.

Human Models

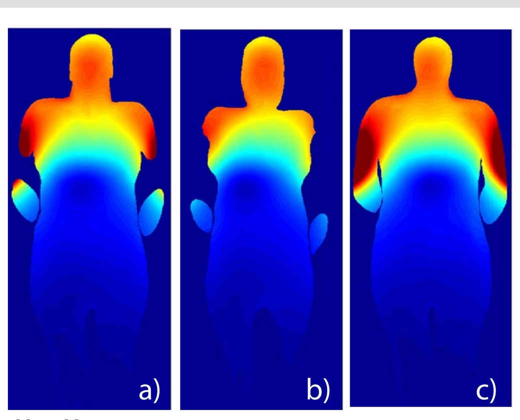
Area of Impact	Nervous System	Musculature	Cardiovascular System	Skeletal System	Circulatory and immune systems
Description of Improvement in VHP v4.	Development of right and left side Sciatic Nerve, Ulnar Nerve, Radial Nerve and Median Nerve. Addition of VHPC Spinal Cord Cauda Equina. Highly refined and accurate CSF, spinal cord grey matter, spinal cord white matter.	Addition of individual bottom, top and mid right and left Abdominals structures. Inclusion of left and right Forearm Flexors and Erector spinae. Addition of Pectoralis major/minor left/right	Extension of upper and lower structures to increase anatomical accuracy in the cardiovascular system.	Refinement of left and right side ribs (#2, 7-9) and corresponding cartilage. Addition of left and right Clavicle. Improvement of phalanges, Sternum and cartilages.	Development of Spleen.

The VHP-Female v.2.2 model includes 184 individual tissue parts, in the form of finite-element triangular surface meshes with approximately 130,000 triangles total. The v.4 model included 254 individual tissue parts, in the form of 750,000 triangles total with much more extensive definition in the cranial region. Tissue electrical properties were derived from the IT'IS Database for electromagnetic parameters of biological tissues [4].

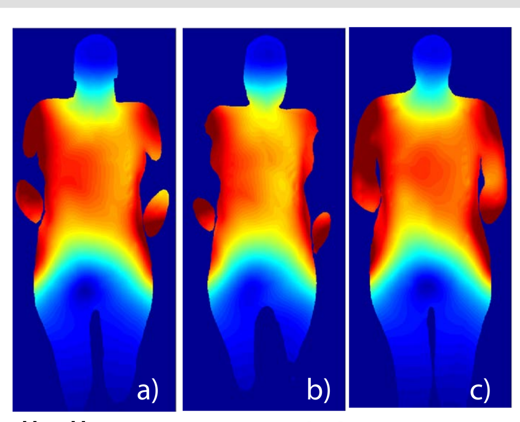
Results



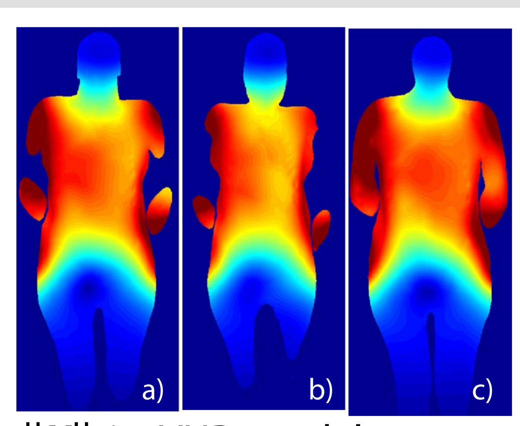
||***H***|| in VHP model v. 2.2 at head landmark: a) Y = 0 mm; b) Y = -30 mm; c) Y = 30 mm.



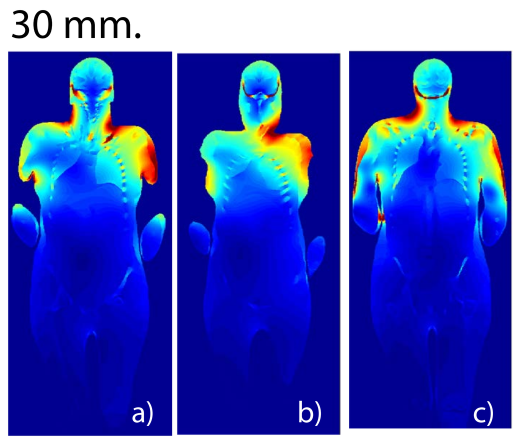
||***H***|| in VHP model v. 4 at head landmark: a) Y = 0 mm; b) Y = -30 mm; c) Y = 30 mm.



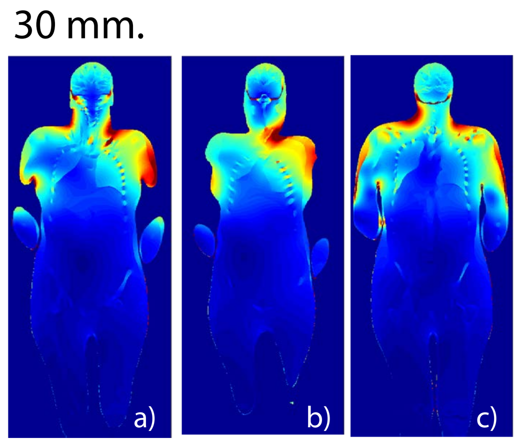
||***H***|| in VHP model v. 2.2 at torso landmark: a) Y = 0 mm; b) Y = -30 mm; c) Y = 30 mm.



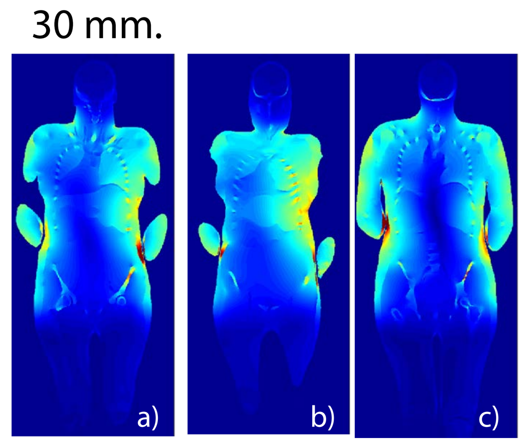
||***H***|| in VHP model v. 4 at torso landmark: a) Y = 0 mm; b) Y = -30 mm; c) Y = 30 mm.



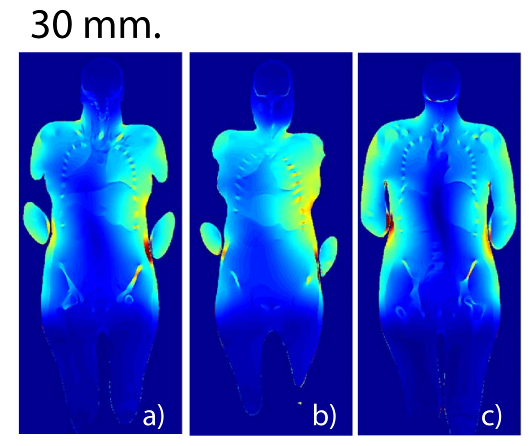
||***E***|| in VHP model v. 2.2 at head landmark: a) Y = 0 mm; b) Y = -30 mm; c) Y = 30 mm.



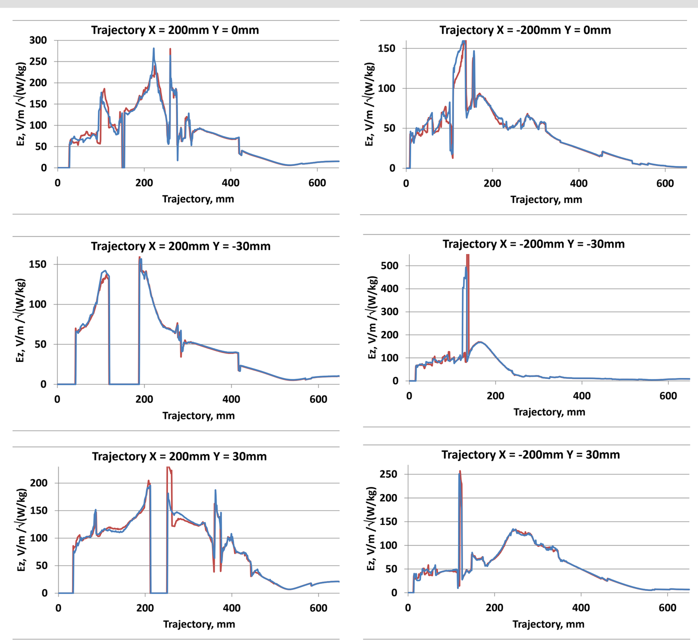
||***E***|| in VHP model v. 4 at head landmark: a) Y = 0 mm; b) Y = -30 mm; c) Y = 30 mm.



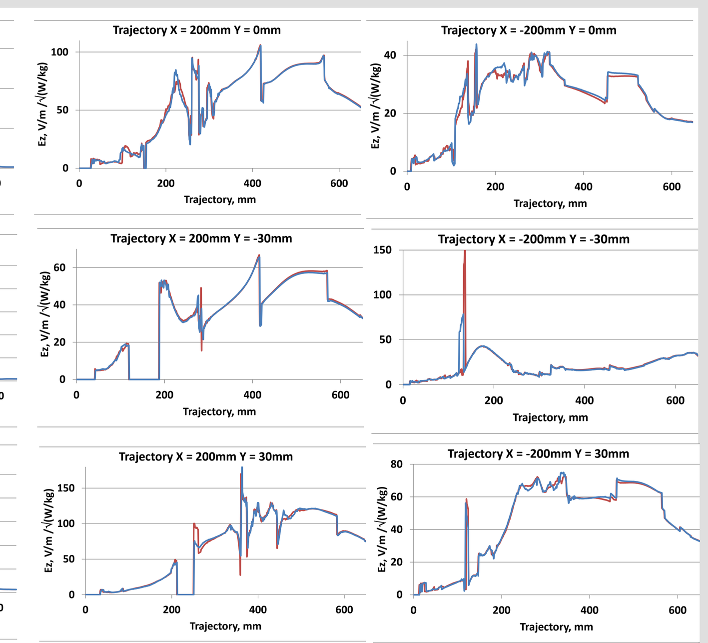
||***E***|| in VHP model v. 2.2 at torso landmark: a) Y = 0 mm; b) Y = -30 mm; c) Y = 30 mm.



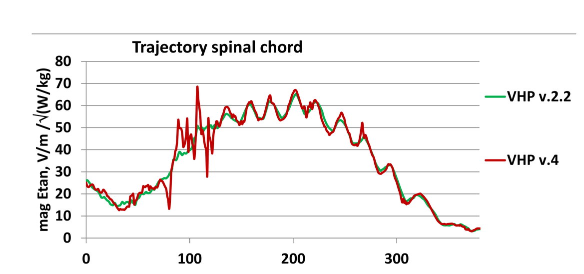
||***E***|| in VHP model v. 4 at torso landmark: a) Y = 0 mm; b) Y = -30 mm; c) Y = 30 mm.



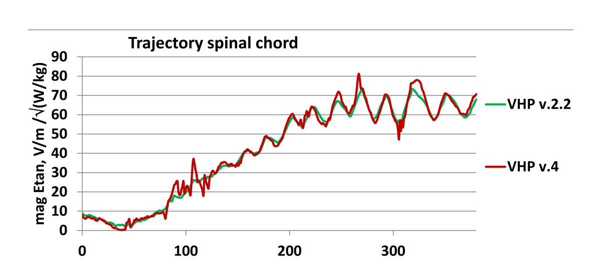
||Etan|| at head landmark along six (x,y) trajectories in the z direction.



||Etan|| at torso landmark along six (x,y) trajectories in the z direction.



E_{tan} in VHP model at head landmark.



E_{tan} in VHP model at torso landmark.

Conclusions

- ❑ **The simulation times for VHP v.2.2 and v.4 were different by a factor of four.**
- ❑ **The VHP model asymmetry resulted in an asymmetrical electromagnetic field generated at both landmark positions.**
- ❑ **On coronal planes analyzed, no substantial difference between electromagnetic fields generated in VHP v.2.2 and VHP v.4 was observed.**
- ❑ **E_{tan} along spinal cord depended slightly on model refinement.**
- ❑ **Some more substantial differences in E_{tan} were observed along six (x,y) trajectories in the z direction.**
- ❑ **Results obtained using a human model representing a single body type are not sufficient for drawing a final conclusion on the level of model refinement required for MRI safety assessment. Further analysis should be conducted to cover diversity in the human population and MRI coil variety in order to make a final decision.**

References

[1] M. Kozlov; P. -L. Bazin; H. E. Möller; N. Weiskopf, "Influence of Cerebrospinal Fluid on Specific Absorption Rate Generated by 300 MHz MRI Transmit Array," Proc. 10th European Conference on Antennas and Propagation (EuCAP) 2016, Davos, Swiss [2] J. Yanamadala, et. al, "New VHP-Female v. 2.0 Full-Body Computational Phantom and Its Performance Metrics Using FEM Simulator ANSYS HFSS," Proc. IEEE EMBC 2015, Milan, 2015. [3] M. Kozlov, R. Turner, "Fast MRI coil analysis based on 3-D electromagnetic and RF circuit co-simulation," J. Magn. Reson., vol. 200, pp. 147-152, Sep. 2009. [4] The Virtual Population (ViP) models. https://www.itis.ethz.ch/virtual-population.