Numerical study of currents in occupational workers induced by body-motion around high-ultrahigh field MRI magnets

S. Crozier[1], A. Trakic[1], H. Wang[1], and F. Liu[1]

[1]The School of Information Technology and Electrical Engineering, The University of Queensland, Brisbane, Queensland, Australia

Synopsis: In modern MRI, occupational workers are exposed to strong, non-uniform static magnetic fields generated by the main superconducting magnet. Previous studies have indicated that movement of the body through these fields can stimulate *in situ* electric fields/ current densities approaching physiological significance. The relationship between the magnetic field pattern/strength and the current distribution/level induced in the body is not well understood. This paper presents numerical evaluations of electric fields/currents in tissue-equivalent, whole-body male and female human models (occupational workers) at various positions and a variety of normalized body motions around three superconducting magnets with central field strengths of 1.5T, 4T and 7T. Possible correlations between the magnetic field characteristics and the induced current density distribution are described and simulations show that it is possible to induce electric fields/current densities above the ICNIRP and IEEE safety standards when the worker is moving very close to the magnets.

Method: Both male (NORMAN) and female (NAOMI) ~2 mm - resolution inhomogeneous voxel phantoms [1] were used in this numerical study. The simulations involved are computationally intensive, therefore, a lower resolution body model at ~ 8 mm was employed first to efficiently estimate the fields induced in the tissues at various positions around the MRI magnet, after which a higher resolution body model was used for more detailed field evaluations. The three static superconducting MRI magnets are the 1.5T Infinion [2] (shielded), 4T Siemens (shielded) and 7T EMI research magnet (unshielded). Figure 1 illustrates the magnetic field profiles of the three magnets. The computation of induced electric fields and associated current densities is based on an in-house developed and validated quasi-static finite-difference method; full details are given in [3-4].

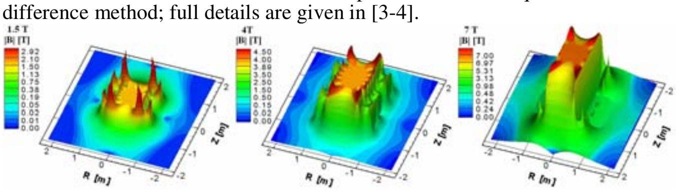

Figure 1 –Total magnetic field profile generated by the 1.5T, 4T and 7T magnets.

In all of the simulations carried out in this study, the velocity has been normalized to 1 ms^{-1} and assumed to be constant throughout the body model. In that way the results obtained can be linearly extrapolated to other velocities of interest with ease. Several cases of body movement are considered (figure 2 - left).

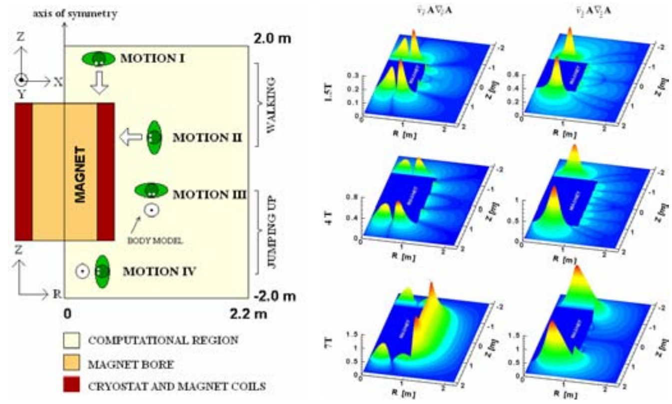

Figure 2 – Left: sketch of four assumed body motions around the magnet of interest; Right: product of the vector magnetic potential and its spatial gradient for normalized motion I and II around the three magnets, which is hypothesized to a potential predictor of worst induction.

Results and discussion: The predictor field profiles in figure 2 (right) agree well with the peak current density *J99* field distributions (limits exceeded in 1% of body voxels) illustrated in figure 3 for all combinations of magnets and body motions. In general, the levels of peak current density increase for increasing static field strength and are larger when the body is aligned parallel (Motion I and III) rather then perpendicular (Motion II and IV) to the magnet z-axis.

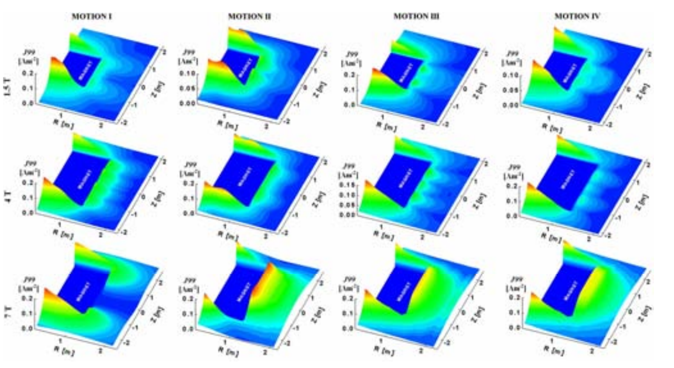

Figure 3 - Peak *J99* field profiles around the three magnets recorded during different body motions (I-IV) of the male. Similar profiles are obtained for the female body motion.

The maximum 1 cm^2 - averaged current densities for most combinations of magnets and motions can be larger than the threshold of 56.57 mAm^{-2} - peak defined in the ICNIRP and EU Directive 2004/40EC guidelines [5-6].

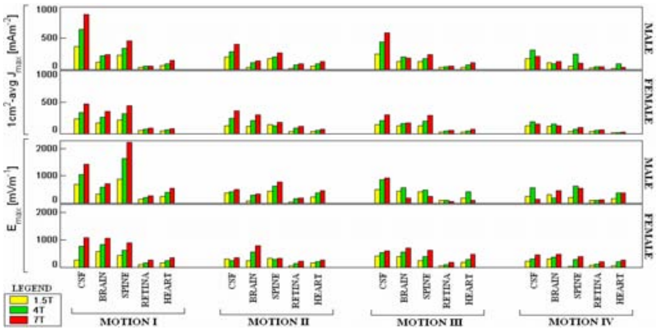

Figure 4 – Maximum induced electric field and 1 cm^2 - averaged current densities in selected tissues of male and female body models for all combinations of magnets and motions.

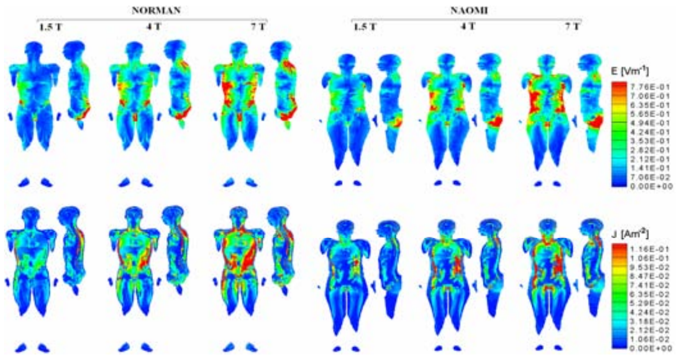

Figure 5 – 2mm–resolution coronal and sagittal electric field (top row) and current density (bottom row) distributions in the mid-planes of the male (left) and female (right) body models obtained during motion I at the worst-induction locations around the three magnets. The figure demonstrates the increase in induced fields as the field strength of the main magnet is increased.

In order to conform to these safety standards, for normalized motion of 1 m/s, the worker should be at least ~ 0.5-1.0 m axially away from the 1.5-7 T magnets, as illustrated in figure 6.

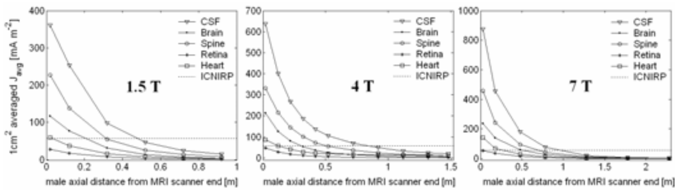

Figure 6 – Maximum 1 cm^2 - averaged current densities in selected tissues of the male body model at different field strengths versus axial distance from the particular MRI scanner end.

The pre-synaptic depolarization threshold of 74.95 mV/m-peak for retina [7] might be exceeded at strengths above 4T for both male and female. However the magnitudes of maximum induced electric fields in the heart are below the IEEE threshold of 1.33 V/m-peak [7] for all examined field strengths

Conclusion: To comply with regulatory limits, occupational workers need to ensure slow movement in specified regions around MRI systems.

Acknowledgements: The authors thank Dr. P. Dimbylow of HPA (UK) for providing the body models and Oxford Magnet Technology for providing the 4T coil pattern. Financial sponsorship by the UK Health and Safety Executive and project management by MCL are gratefully acknowledged.

Refereneces:

[1] P.J. Dimbylow, *Phys. Med. Biol.,* **45**: 1013-1022, 2000
[2] Yu-C N. Cheng *et al.* , MAGMA., **16**:57-67, 2003
[3] S. Crozier and F. Liu, *Prog. Biophy. Molec. Biol.*, **87**: 267-278, 2005
[4] F. Liu *et al*, *IEEE Trans. Biomed. Eng.*, **50** (7): 804-815, 2003
[5] ICNIRP, *Health Phys.,* **74**: 494-522, 1998
[6] Directive 2004/40/EC, *Official J. European Union,* L **159**, 2004
[7] IEEE C95.6, New York, 2002