# Modelling regulatory compliance of occupationally exposed MRI workers during gradient pulsing

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**Synopsis:** Magnetic resonance technology employs a wide range of electromagnetic fields for rapid generation of high-resolution anatomical images. These electromagnetic fields are known to interact with living tissue in different ways and mechanisms causing potentially detrimental physiological effects. This study presents numerical investigations into the magnitudes and spatial distributions of induced *in situ* electric fields and associated current densities in tissue-equivalent, whole-body, male and female models of occupational workers when standing close to the ends of three cylindrical gradient coils. The results have been compared to the most recent IEEE, ICNIRP and EU-Directive 2004/40/EC standards for magnetic and electric field exposure in controlled environments.

**Methods:** The computation of the scalar electric potential and thus the secondary electric field is performed with the previously developed, efficient, quasi-static finite-difference (QSFD) scheme, full details can be found in [1]. The complete computational method outlined herein has been verified against other known solutions as in [2]. Longitudinal and transverse actively-shielded, whole-body, symmetric gradient coils are used in this investigation to compute the electric fields and current densities induced in the described body models during gradient switching. It is assumed throughout that each coil generates normalized gradient field strength of 1 *mT/m* in the working volume. In that way the simulation results can be linearly extrapolated to field strengths of interest with ease. It is also assumed that the gradient coil current is pulsed trapezoidally at the frequency of 1 *kHz* and 100 *μs* rise-time. Harmonic analysis of the trapezoidal excitation has been performed assuming Fourier integration. The magnetic fields generated by the three gradients near the coil ends represent the major risk areas due to worker access. As shown in Fig. 1, in all simulations the voxel phantoms are positioned so that they are facing the gradient coil end of interest. Both the male and female phantoms are assumed stationary for the purposes of these studies. A 1% - thresholded total electric field and current density scheme by Dawson and authors [3] have been used for a robust estimate of maximum field levels. The phantoms are moved around this region at spatial increments of 0.2 *m* both radially and axially and the fields induced in low-resolution (8 mm) body models are evaluated. Once the position of maximum induction was located, higher resolution (2 mm) simulations were performed. A total of five simulations were performed for each gradient coil individually and for the combination of all three coils, and the electric field and current densities were recorded for all tissues. The results of these simulations are illustrated as graphs of 1 $cm^2$ averaged current densities in tissues of CNS, heart, muscle, skin and fat. The purpose of this series of simulations is to estimate the distance away from the gradient set at which the induced 1 $cm^2$ averaged current densities in significant tissues are below the ICNIRP standard of 10 $mAm^{-2}$ – rms (actually 13 $mAm^{-2}$ for the incident waveform accounting for the higher limits on higher frequencies).

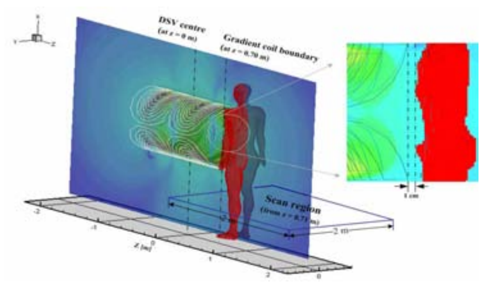

**Fig.1 –** Sketch of the male body model in a typical upright standing position and orientation near the x-gradient coil end.

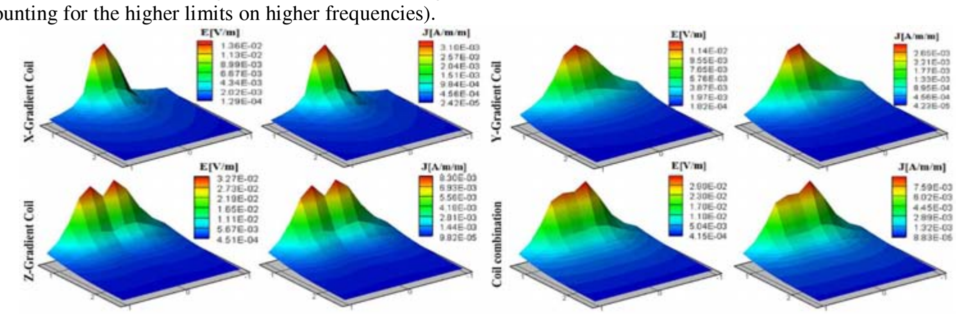

**Fig.2 –** Records of 1%-thresholded electric fields (left), current density (right) induced somewhere in Norman versus spatial position around the three gradient coils when considered individually and for the combination of all three gradient coils.

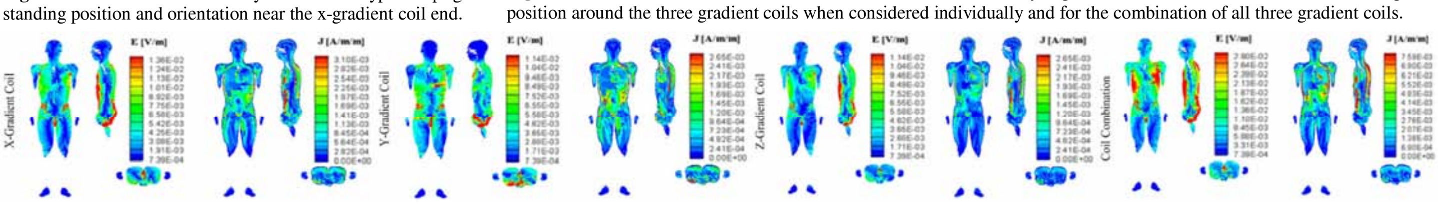

**Fig.3 –** High-resolution coronal, sagittal and axial electric field (left column) and current density (right column) distributions in the male voxel phantom for different gradient field.

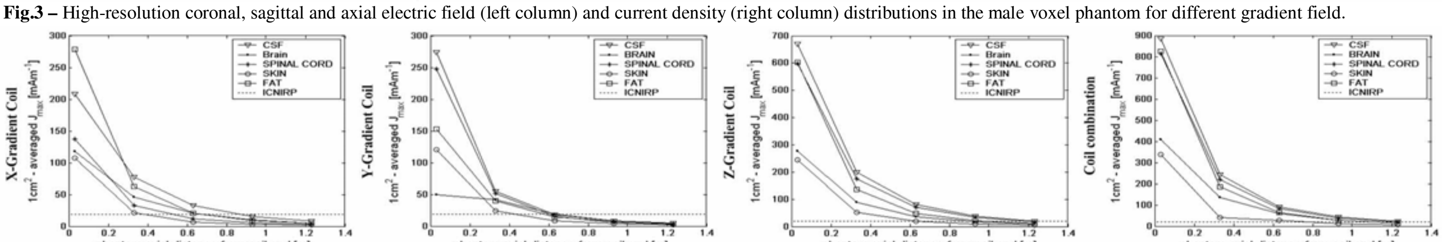

**Fig.4 –** Maximum 1 $cm^2$- averaged current densities induced in selected tissues of the male (left column) and female (right column) body models versus axial distance from the ends of three gradient coils (first three rows) and the combination of all three gradient coils (last row). Results have been scaled to the commonly operated central field strength of 40 mT/m.

**Results and Discussion:** Fig 2 shows the profiles for male body model in scan region. From these results we note that, in case of the transverse gradient coils, the largest induced fields appear in the central region of the coil entrance. However, for the z-gradient coil and coil combinations, the largest induced fields are close to the coil edges as two distinct peaks in E and J are evident at ~r = 0.2 *m*. High values of induced electric field are notable on the front and lower back surfaces of the trunk (fig 3) with low electric field values in the middle of the body. Furthermore, according to selected results shown in fig 4 (for tissues of CNS, heart, skin, fat and muscle), it is estimated that both male and female occupational workers should be at least ~1 m axially away from the gradient coil ends to bring the exposures within regulatory limits. The methodology presented in this paper can be extrapolated to other dynamic field strengths for the evaluation of the effects at various positions.

**Conclusion:** In these theoretical investigations, we have computed the electric fields and current densities induced in whole-body male and female models of occupational workers near the entrance of longitudinal and transverse actively shielded symmetric gradient coils. The objectives of the research reported here are to evaluate several worst-case exposure scenarios and to estimate the axial distance from the coil end where the maximum induced current densities are below the defined safety limits. It is hoped that this study will help in the evaluation of the regulatory compliance involved with occupational workers and patients when standing close to the ends of gradient coil systems.

**References:**

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[3] T. W. Dawson, K. Caputa and M. A Stuchly, *Physics in Medicine and Biology*, **47**: 995-1012, 2002

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