

Evaluation of ISO/IEC JWG Tier 3 Approach for RF Heating in 1.5 MRI with Implantable Cardiac Rhythm Devices

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Introduction

MRI scans have been contraindications for patients with pacemakers or ICDs due to safety reasons. Induced currents along the leads due to radio frequency (RF) fields during MRI scans pose high risks for causing direct rapid cardiac pacing and heating in the tissue. The ISO/IEC Joint Working Group (JWG) has developed the tiered approaches to establish the worst case RF heating conditions for active implantable devices utilizing computer simulations. Lower in tier, the more stringent is the criteria amongst the four tiers. The tier 3 utilizes the maximum tangential electric field averaged over a 2 cm (max Etan) path length along clinically relevant lead paths. We evaluated the applicability of the ISO/IEC JWG tier 3 method to implantable cardiac rhythm devices in five human body models of obese male (Fats), adult male (Duke), adult female (Ella), girl (Billie), and boy (Thelonius) by comparing max Etan and maximum of rms tangential electrical fields defined over lead paths (Erms).

Methods

The SEMCAD software package was used to calculate the electric field distribution within five human subject models (Figure 1) due to RF fields from high pass and low pass MRI birdcage coils. The body models were discretized in SEMCAD software with cubical finite-difference mesh cells of length 2.0 mm. The simulation conditions also included a total number of 2161 lead pathways, circularly polarization field rotations (counter clockwise and clockwise), body positions inside RF coils, tissue properties and RF coil size etc. Each of the five body types were simulated at multiple landmark positions along the Z-axis with increment in Z of 100mm. The tissue conductivity and permittivity were varied $\pm 20\%$ of nominal values. All the fields were scaled to 2W/kg whole body SAR. The obtained Etan values along various clinical paths were extracted from 174,960 simulations, and then each Etan was averaged over 2 cm path length to remove potential simulation singularity the same as ISO/IEC JWG tier 3. The maximum Etan and Erms where $E_{rms}^2 = \int_0^L |Etan(l)|^2 dl / L$ along each path per simulation were obtained. The comparisons between max Etan and max Erms per simulation variables (i.e. body types, body position etc) were made.

Results

Figure 2 shows the max Etan and max Erms for all the simulation variables with correlation coefficient $R^2 = 0.8716$ and slope of 2.743. Clearly for any data points in Figure 2, max Etan was greater than max Erms which indicates max Etan values over-estimated max Erms within each simulation variable. Since Erms also could be the upper limit for electric fields in tissue near an implant lead [1], max Etan would lead to over-estimate the temperature rise in the tissue. The overall max Etan is 260 ± 126 V/m in a range of 56 V/m to 570 V/m and max Erms is 98 ± 43 V/m in a range of 19 V/m to 226 V/m with 2W/kg whole body SAR, where the global max Etan of 570 V/m is about two times greater than global max Erms of 226 V/m.

Conclusions

The maximum value of Etan along clinically relevant pathways computed through 174,960 simulations was much higher than the max Erms. Knowing tier 1 and tier 2 are even more stringent than tier 3, this work indicates that the ISO/IEC JWG tiers 1-3 are over conservative for implantable cardiac rhythm devices. For the worst case RF heating, Tier 3 overestimates the effective E by a factor of more than 2 or a factor of 4 in heating.

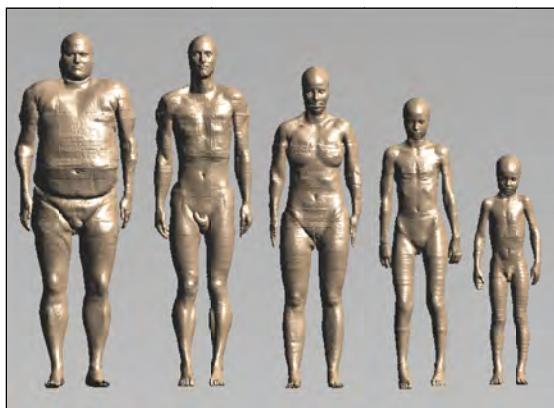


Figure 1: Human Subject Models

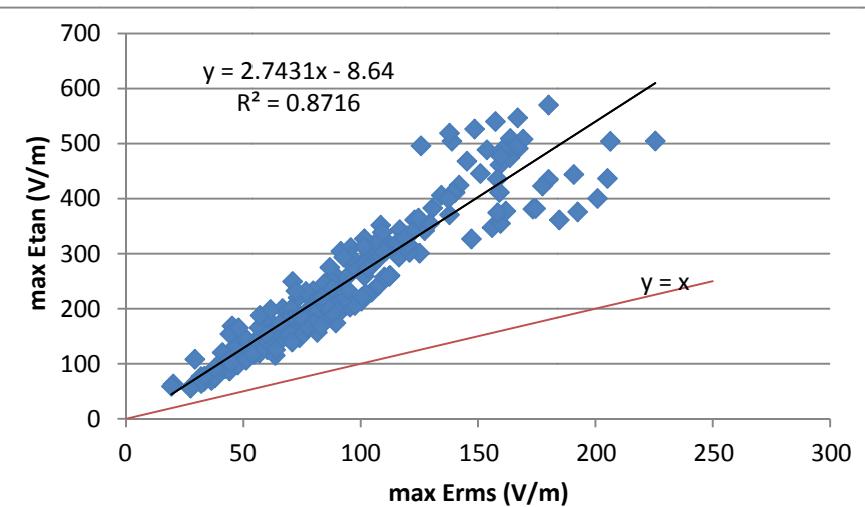


Figure 2: Max Etan versus max Erms in each simulation variable

- 1) Park et al. Calculation of MRI Induced Heating of an Implanted Medical Lead Wire With and Electric Field Transfer Function. *JMRI* 26:1278-1285 (2007)