Modeling occupational exposure to RF and gradient fields associated with an interventional procedure in an open 1 T MR system

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INTRODUCTION. European Union Directives 2004/40/EC and 2008/46/EC require a risk assessment of occupational exposure to electromagnetic fields to be carried out. Some MR procedures may involve exposure of staff to electric and/or magnetic fields and/or magnetic flux density values that exceed action values (AVs) defined in the Directives, in which case calculations of specific absorption rate (SAR) and current density (***J***) within the body are required to ensure compliance with the defined exposure limit values (ELVs). In this work we investigate the use of numerical dosimetry to assess occupational exposure to RF and gradient fields associated with an interventional procedure carried out in an open 1 T scanner.

METHODS. The procedure considered in this work required a radiologist to lean into a 1 T open system (Panorama HFO, Philips Medical Systems) to place a clip in the breast of a patient (fig 1). Real time imaging with a balanced TFE sequence is used and the radiologist is adjacent to the patient for a period of approximately 30 s. Since previous measurements of the E- and H- components of the RF field and the switched gradient fields had indicated that these parameters could exceed the relevant AVs at and around the position of the radiologist [1], numerical modelling of this exposure was required. Generic models of the RF and gradient coils were provided by the manufacturer under a non-disclosure agreement and the scanner, its location within the screened room, and the walls of the room with dimensions 7.1 m x 5.5 m x 2.69 m were included in the numerical model (fig 2). An anatomically realistic voxel model of an adult male (TIM) [2,3] was used. Since this was not articulated, only an approximation of the radiologist's upper body position within the scanner could be achieved (figs 2,3). Two numerical methods (FDTD and FIT) implemented in commercial software packages (SEMCAD X v13.2 and the transient solver within CST Microwave Studio v2008) were used to simulate exposures to the RF and gradient fields. The latter was simulated using both the low frequency solver and the frequency scaling method in the respective packages. Tissue properties used were those reported by Gabriel et al [4-6]. SAR (whole body and averaged over 10g of tissue), E-field ***E***, and current density ***J*** within the body were calculated.

RESULTS. Fig 4 shows the SAR_{10g} distribution within the TIM model due to the RF coils, calculated using FDTD and normalized to the maximum value which occurred in the neck arc. When scaled to previously measured values of the field [1], the maximum SAR_{10g} was 0.44 W/kg and the whole body SAR was 0.053 W/kg. Fig 5 shows the E-field distribution due to the z-gradient coil driven at 1 kHz, calculated using FS/FIT, within coronal plane that contained the maximum single voxel E-field (0.74 V/m RMS) which occurred in the skin of the head. Fig 6 shows the ***J*** distribution in the centre plane of the TIM model due to the z-gradient coil driven at 1 kHz and obtained using the low frequency solver within SEMCAD X. The maximum single voxel value in CNS tissue was approximately 1.2 A/m^2 RMS. Maximum values due to the x- and y- gradient coils were approximately half of this value. The maximum values of ***J*** and ***E*** given above assume the maximum gradient achievable (26 mT/m).When scaled to previously measured dB/dt values, the maximum ***J*** in CNS tissues (averaged over 1 cm^2) due to the x-, y- and z-gradient coils was estimated to be 87, 85 and 140 mA/m^2, respectively.

CONCLUSIONS. Maximum values of local SAR_{10g}, whole body SAR, ***J***, and internal E-field within a body model in a position in a 1 T open scanner representative of this interventional procedure were calculated. The whole body SAR and SAR_{10g} were compliant with the relevant ELVs in the EU Directives 2004/40/EC and 2008/46/EC. However, the ELV relevant to the frequencies observed in switched gradient fields (10 mA/m^2) was exceeded in this scenario by more than an order of magnitude. The maximum E-field (averaged over 5 mm) induced in the body by the switched gradient fields was compliant with safety guidelines recommended by IEEE [7].

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Fig 1

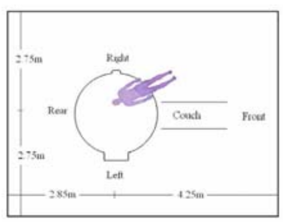

Fig 2

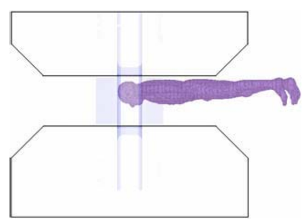

Fig 3

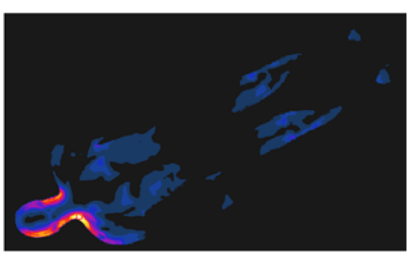

Fig 4

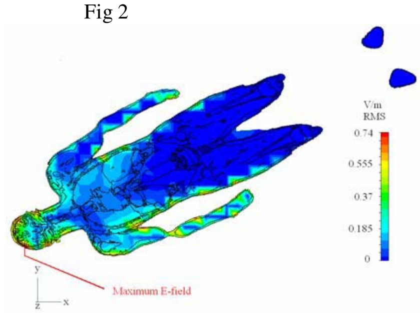

Fig 5

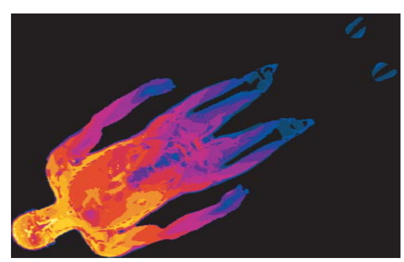

Fig 6

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