3D simulation of electromagnetic fields inside the human body for applications of MR and EPR: Effects of object size and frequency on RF field homogeneity

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Introduction:
The knowledge of the RF field amplitudes inside biological objects of human scale is important in clinical diagnosis based on magnetic resonance methods. The frequency and object size dependent properties of the magnetic B1 field set upper limits for applications of MRI at high Bo static magnetic fields [1,2] and of the frequency used for electron spin polarization in Overhauser enhanced MRI [3-5].
The amplitude pattern of the B1 field reflects the image uniformity and the attainable locally varying signal to noise ratio. The variation of the RF field amplitudes increases at high frequencies and for large body sizes which leads to excessive power deposition with possible hot spots. The distribution of RF heat deposition also plays an important role in whole body hyperthermia therapy [6].

Simulations of these effects have been reported by Jin et. al. [7] for the human head. To demonstrate the effects resulting from the diversity of the larger sized human trunk, we present 3D FEM field calculations using different absolute cross sectional dimensions of the body at frequencies between 70 MHz and 280 MHz.

Method:
Calculations of the electromagnetic fields inside dielectric objects are performed using a 3D finite element analysis software program (FEM Emas Ansoft Corp.). The finite element model (FEM) uses a non resonant 16 rod TEM resonator structure [8], diameter 58 cm and length 28 cm, the shield diameter is 68 cm. The diversity of the human trunk is modelled with cylindrical objects of 60 cm length having three different elliptical crosssections, 28x20, 38x26, 45x30 cm. The permittivity ε and conductivity σ of the cylindrical object are varied in the calculations using literature data [9]. The calculations deliver results for linear and circular polarizations. Due to the centered ground of the TEM rods electric fields are minimized. The total number of finite elements in the model is 17000.

Results:
The calculated normalized B1 magnetic field distribution along a diagonal line for the medium sized cross section is shown in Fig.1. Here the inhomogeneity increases with frequency. The standing wave pattern result from dielectric resonance effects in the object which are smoothed due to the conductivity of the object. Test calculations for the empty TEM coil show uniform B1 fields. The highest B1 field occurs in the center for all frequencies. At 234 MHz a B1 variation of 8 dB is found. The B1 inhomogeneity and standing wave effect increases with larger crosssectional area and with increasing frequency. The ratio of maximum to minimum B1 is large for transversal and sagittal slices and less pronounced in coronal slices.

Fig.2. shows the 3D FEM simulation of the B1 field in the center transversal slice of a loaded horizontally polarized linear coil at 170 MHz. Here the B1 magnetic field is high in the center and in some regions near the surface, between these regions two stripes form areas of low B1 field. This property is qualitatively found in the transversal MR spin echo body image acquired at 4 T (Fig.3.).

Conclusion:
For frequencies beyond 100 MHz dielectric resonance or standing wave phenomena rather than the exciting field pattern of the RF coil determine the electromagnetic field distribution inside the human body. Strong variations of the magnetic B1 field and localized SAR spots limit the usable upper EPR frequency for electron spin polarization in Overhauser enhanced whole body MRI to about 140 MHz. This limit also holds for large scale body imaging at high values of the static Bo field between 3 T and 4 T.

Fig. 1: Normalized magnetic field B1 versus the diagonal of elliptical object with crosssection of 38cmx26cm.

Fig. 2: Magnetic field (A/m) contour plot of loaded horizontally linear polarized birdcage coil at 170 MHz.

Fig. 3: MR body image, FOV 40 cm, measured at 4 T (170 MHz).

References: