RF power absorption in mother and fetus associated with exposure to B1 field from a birdcage body coil at 3T

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INTRODUCTION

Although there is no indication that the use of clinical MR procedures during pregnancy produces adverse effects, there is currently a significant level of uncertainty regarding the risk posed by MRI examinations to pregnant patients [1-3]. The most frequently used methods, single shot Fast Spin Echo (ssFSE), often require operation at the limits imposed by safety guidelines and, with the introduction of higher field systems, such limits will be even more significant for fetal imaging. In this preliminary study we consider Specific Absorption Rate (SAR) in an anatomically realistic model of a pregnant patient associated with the RF magnetic field from a birdcage body coil typical of a 3T MRI system (i.e. operating at 127 MHz) by using a commercial electromagnetic solver based on the finite integration technique [4] (CST Microwave Studio®, Computer Simulation Technology, Darmstadt).

METHOD

The circular birdcage coil was 600 mm in diameter, the end rings were 10 mm wide, and their centre-centre spacing was 400 mm. The 16 rungs each consisted of a rod, 10 mm square in cross-section, with its centre located on a radius of 300 mm. In each rung, 4 capacitors, each C_{rung} pF, were inserted into 5 mm gaps created (a) between the end rings and the ends of the rung, and (b) at ±55 mm from the rung centre (at z=0). 30 pF capacitors were inserted into 16 similar gaps created in each of the end rings, mid-way between the rungs. Additional 5 mm gaps were created at the centres of the 2 rungs located at angular positions 225^o and 315^o relative to the vertical (y-) axis. The coil was driven in quadrature by applying voltages (equal amplitude, 90^o phase difference) across these gaps. A cylindrical RF shield (internal radius 339 mm, outer radius 340 mm) 1000 mm long was positioned concentrically with the coil. The conductivity of all conductors was taken to be 5.997×10^7 S/m and penetration of the electromagnetic fields into these was simulated by a 1-dimensional surface impedance model.

The mother/fetus model (in this case, including twins) was produced from transverse ssFSE MR images acquired at 23 weeks gestation on a Philips 1.5 T Intera system. These data were segmented to 10 tissue types to form a 3-D data set of 512 x 512 x 26 voxels, each 0.82 mm x 0.82 mm x 10.4 mm, that was imported into the coil model. The tissue model was located centrally within the coil. Tissue dielectric properties were based on the 4-Cole-Cole analysis reported by Gabiel [5] and calculated on-line[6]. Values for fetal tissues were adjusted to account for their higher water. The mother/fetus model and coil are shown in Fig 1.

The model was meshed to 1,111,968 cells and run on a PC with a 3.2 GHz Pentium 4 processor and 3 GB accessible RAM. The loaded coil model was tuned to 127 MHz by observing the computed s-parameters s_{11} and s_{21} and adjusting the value of C_{rung}. The coil was excited by Gaussian voltage pulses 7.3 ns in duration applied at 2 ports as described above. The transient response of the system was simulated using a time step of 0.87 ps and the model was run until the energy had decayed -30 dB. Total CPU tine was approximately 14 hours. The H-field distribution at 127 MHz was calculated by means of a fast Fourier transform and SAR (averaged over the complete tissue model, and over 10 g and 1 g of tissue (SAR_{body}, SAR_{10g}, and SAR_{1g})) distributions were determined.

RESULTS

The relative location within the model of the z-plane in which the maximum values of SAR_{10g} and SAR_{1g} occurred (z=19), and the corresponding tissue distribution are shown in Fig. 2. Fig. 3 shows the SAR distributions in this plane, normalised to the maximum of SAR_{10g} and SAR_{1g}. The maximum SAR values, $SAR_{10g\,max}$ and $SAR_{1g\,max}$, when normalised to a continuous transverse B-field at the centre of the coil (0,0,0) of 1 µT, were 1.06 W/kg and 1.65 W/kg, respectively. These maxima occurred within the mother's pelvic region. The corresponding maximum values within fetal tissues were 0.47 W/kg (SAR_{10g}) and 0.55 W/kg (SAR_{1g}); SAR_{body}, normalised in the same manner, was 0.15 W/kg. For other field conditions, the SAR scales according to the B-field^2 and directly with the duty cycle.

The results can also be interpreted in terms of recommended limits stated in safety guidelines [1-3]. For example, to be compliant with [1], these data suggest that the appropriate limit is the local SAR_{10g} within the trunk (i.e. 10 W/kg); the corresponding SAR_{body} would be 1.37 W/kg and the maximum local SAR_{10g} within the fetus would be 4.5 W/kg. However, the latter value exceeds the limit for fetal exposure (4 W/kg) recommended in [2]. Thus for compliance with [2], the SAR_{body} and SAR_{10g} (within the trunk) would be reduced to 1.22 W/kg and 8.9 W/kg, respectively.

To be compliant with [3], the data suggest that the maximum local SAR_{1g} within the trunk (i.e. 8 W/kg) is the limiting factor. This limit is met when SAR_{body} is 0.7 W/kg, and under these conditions, the maximum local SAR in the fetus is 2.7 W/kg (SAR_{1g}) or 2.3W/kg (SAR_{10g}).

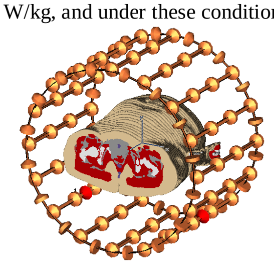

Figure 1: The body coil (excluding RF shield) and tissue model

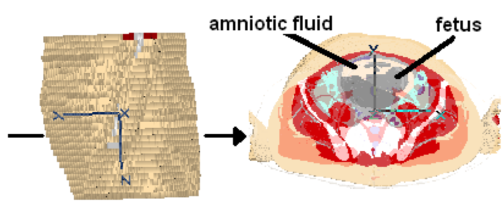

Figure 2: The cross section in which the maximum values of SAR_{10g} and SAR_{1g} occur and its location

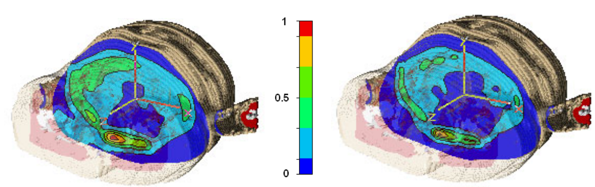

Figure 3: SAR distribution, within the tissue section shown in Fig. 2, normalised to maximum value. Left: SAR_{10g} Right SAR_{1g}

CONCLUSION

This preliminary study of a shortened mother/fetus model provides insight into the SAR distribution associated with a 127 MHz birdcage body coil. The results suggest that highest local SAR is in the mother, with the fetus being exposed to a peak of about half this value. SAR values averaged over 1 g or 10 g of tissue are the limiting factors according to FDA and ICNIRP, respectively. For compliance with MDA, a further restriction is suggested to limit the maximum SAR_{10g} in fetal tissue to 4 W/kg. Although this preliminary tissue model is short, partially fills the coil and lacks skin, these findings warrant further work. A mother/fetus model that represents a larger extent of the trunk and limbs is being developed and modelling of SAR over a range of frequencies used in medium and high field MRI systems is underway.

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