RF exposure and resulting temperature in the fetus during MRI

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INTRODUCTION. There are currently few data regarding fetal heating caused by RF power deposition during MRI examinations of pregnant patients. In this study we predict Specific Absorption Rate (SAR) and temperatures in an anatomically realistic model of a pregnant subject due to exposure to the RF magnetic field from a birdcage body coil at 64 MHz assuming the maternal whole body SAR (SAR_{MWB}) is 2 W kg^{-1}, the limit recommended in safety guidelines [1-4] for normal mode operation.

METHODS. The SEMCAD X v14 (Schmid & Partner Engineering AG, Zurich) FDTD package was used to model a generic, shielded, low-pass, 16 rung circular birdcage coil [5] operating at 64 MHz in quadrature excitation. The conductivity of all conductors was taken to be 5.997×10^7 S m^{-1}.

The whole body human database of the Japanese average pregnant woman (gestational age 26 weeks) jointly developed by the National Institute of Information and Communications Technology, Tokyo and Chiba University [6] was used. It consisted of ~7×10^6 cells, each 2 x 2 x 2 mm^3, segmented into 56 tissue types and was positioned such that the foetal head was centred within the coil. Dielectric properties of the tissues were taken from the literature [5,7]. E- and H-fields and SAR (averaged over the whole body, over 10g tissue, and over tissue types) were calculated.

Heat transfer from fetal to maternal blood in the placenta accounts for ~80% of foetal heat loss [8] and the remaining 20% occurs across the foetal skin/amniotic fluid and amniotic fluid/uterine wall boundaries. The umbilical vein (UV) and arteries (UAs) were modelled discretely within the SEMCAD thermal solver using the DIscrete VAsculature option, enabling the thermal interaction between a vessel and surrounding tissue and the vessel wall temperature to be estimated. Elsewhere temperature distributions were simulated using a Finite Difference method and the Pennes' thermal solver within SEMCAD X v14. A cross section of the umbilical vessels (in the y-z plane) and their relative positions are shown in fig. 1. The volumetric flows in the UV/UAs were 2×10^{-6}, 1×10^{-6} m^3 s^{-1}, respectively. The temperature of blood entering the UV and UAs, and the blood temperature for maternal and fetal tissues, were 37 and 37.5 °C, respectively. At the maternal skin/air boundary the heat transfer coefficient was 10.5 W m^{-2} $°C^{-1}$ and the heat flux was 20 W m^{-2}. The ambient temperature was 24 °C.

RESULTS. For SAR_{MWB}=2 W kg^{-1}, the foetal volume averaged SAR was 1.2 W kg^{-1} and the maximum foetal SAR_{10g} was 5.5 W kg^{-1}. Values of SAR_{10g} > 10 W kg^{-1} were predicted in several maternal tissues within the trunk. The greatest local SAR occurred in the mother's wrist. Temperature distributions were determined every 300 s over a period of 2700 s during which $SAR_{MWB}=0$ for $0 \text{ s} \le t < 900$ s and $t_{exposure} \le t \le 2700$ s, and SAR_{MWB}=2 W kg^{-1} for $900 \text{ s} \le t < t_{exposure}$ where $t_{exposure}$ was set to 360, 600, or 1800 s of continuous RF exposure. Mean and maximum fetal temperatures at t= $t_{exposure}$ and respective temperature increases relative to the baseline were:

		Mean T (°C)	Δ_{MeanT} (°C)	Max T(°C)	Δ_{MaxT} (°C)
fetus (excluding brain):	360s/600s/1800s continuous RF	37.6/37.6/37.7	0.13/0.16/0.24	37.9/38.2/38.9	0.4/0.7/1.4
fetal brain:	360s/600s/1800s continuous RF	37.6/37.6/37.6	0.11/0.15/0.19	37.7/37.8/38.0	0.2/0.3/0.5

Fig. 2 shows predicted temperatures *v.* time for fetal tissues and amniotic fluid resulting from a continuous SAR_{MWB}=2 W kg^{-1} for 360 s. In practice, the interpretation of predicted local maximum temperatures is difficult since the fetus moves frequently. However, for continuous RF exposure over periods typical of those in clinical examinations (say < ~600s), fetal temperature is predicted to be ≤ 38 °C when $SAR_{MWB} \le 2$ W kg^{-1}. An example of SAR *v.* time from a clinical fetal procedure is shown in fig. 3; the mean SAR over 4200 s was 0.75 W kg^{-1}. The predicted mean temperatures in fetus/fetal brain at t=4200 s were 37.6/37.6 °C, with corresponding maximum local temperatures 37.9/37.7 °C.

CONCLUSIONS. These results suggest that foetal heating due to exposure of this pregnant patient model to the RF field of a 64 MHz body coil operating within the normal mode at the maximum recommended maternal whole body averaged SAR is compliant with safety guideline limits.

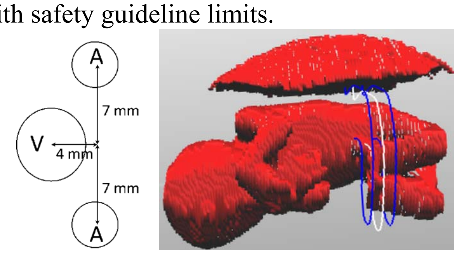

Fig. 1

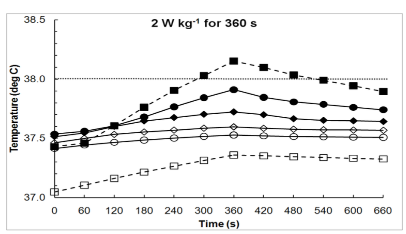

Fig. 2

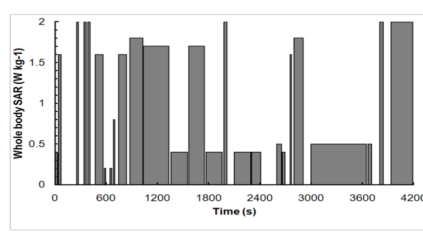

Fig. 3

Fig 1: Relative positions of umbilical vein (V) and arteries (A). Right: Perspective view of foetus and placenta showing the tracks of the two umbilical arteries (outer vessels) and vein (central vessel). The vessels were generated by extruding the cross sections shown on the left along these tracks. **Fig 2:** Temperature versus time for fetal tissues and amniotic fluid. Fetus: mean T (○), max T(●); Fetal brain: mean T (◇), max T(◆); amniotic fluid: mean T(□), max T(■). **Fig. 3:** Maternal whole body SAR *versus* time - data from a clinical fetal examination

References

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