SAR and temperature rise evaluation for pregnant woman models during MRI

D. Wu[1], J. Chen[1], W. Kainz[2], and S. Wang[3]

[1]Department of Electrical and Computer Engineering, University of Houston, Houston, TX, United States, [2]FDA, MD, United States, [3]NIH, MD, United States

Introduction

MRI radio frequency (RF) radiations safety standards for humans were developed based on adult male models. Their applicability to pregnant women or fetuses needs to be investigated since the fetus is typically surrounded by high-conductive liquid. In this study we performed a detailed numerical investigation to calculate the specific absorption rate (SAR) and the temperature distribution within a series of pregnant woman models undergoing MRI procedures.

Methods

Simulation Method: The simulation method used in this study was based on the finite-difference time-domain (FDTD) scheme applied to both the Maxwell's equations and the bio-heat equation. First the electrical simulation calculated the specific absorption rate (SAR) due to the RF field of a MRI birdcage coil. The SAR distribution was coupled to the thermal simulation and the temperature increase within the pregnant woman models was calculated. Bulk tissue perfusion was included to account for blood flow in the woman and the fetus. For the thermal simulation it was necessary to first calculate the basal temperature distribution within the pregnant woman models. Simulation Models: The nine pregnant woman models used in this study were co-developed by the University of Houston and the Food and Drug Administration (FDA), and are shown in Figure 1. Two women body models, one describing the shape of the body surface of a pregnant woman in the 34th gestational week and the other describing a non-pregnant female body surface, were used. The fetus, bladder, uterus, placenta and bones based on MRI data of a woman in the 35th gestational week were scaled in size to gestational stages from the first to the ninth month. The electrical and thermal properties of these models were obtained from the literature. Simulation Setup: A MRI birdcage coil was designed using the birdcage builder software version 1.0 developed by Pennsylvania State University. The coil is composed of two end-rings connected by 16 equally spaced rungs. Each rung is split, and a capacitor is placed inside the gap. As in most real MRI systems our coil is also surrounded by an RF shield. Each model was aligned such that the woman was placed on a bed in supine position with the back of the model 22.7 cm away from the inner edge of the coil and the navel at the center of the coil. After placing the models within the MRI coil, the capacitors were re-tuned to achieve resonance at the MRI operating frequency.

Results

Simulations were carried out for 1.5T and 3T MRI systems for both normal and first level controlled operating modes. We calculated the maximum 10-gram cubical averaged SAR and the maximum temperature within various tissues. All values were normalized to the IEC 60601-2-33 whole-body averaged specific absorption rate limit of 2 W/kg or 4 W/kg, respectively. Figures 2 and 3 show the maximum 10-gram averaged SAR and the maximum temperature rise for each tissue at different pregnant stages for the first level controlled mode at 64 MHz. At this operating mode, the maximum energy depositions within the fetus exceeded the 10 W/kg limit after the fourth month of pregnancy. The maximum allowed temperature for the body was exceeded for women greater than sixth months pregnant. In addition, the maximum fetus and amniotic fluid temperatures exceeded the limit after the fifth month. However, the maximum SAR and temperature were found to be within the limits of the MRI system when operating in its normal mode. The core temperature limits, defined as the average over the fetus or the whole body, for both operating modes and both frequencies were not exceeded.

Conclusions

We found an increase in specific absorption rate and temperature at the later stages of pregnancy. Based on the results of this study radiologists can minimize local fetus heating, especially late in pregnancy, by using normal mode sequences which minimize the whole body SAR in the mother.

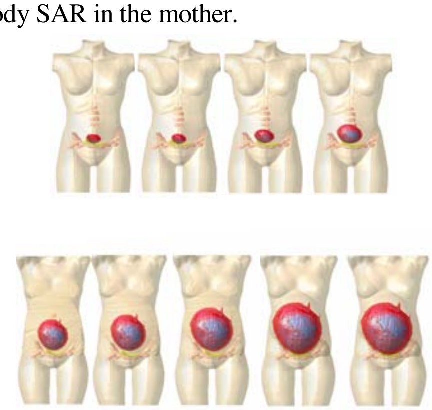

Figure 1. Nine pregnant woman models used in this study.

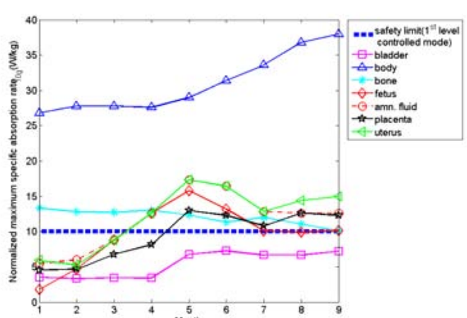

Figure 2. Normalized maximum 10-g averaged specific absorption rate (64-MHz first-level controlled mode) a function of pregnant stage.

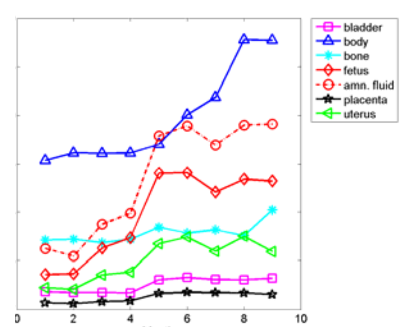

Figure 3. Maximum temperature within different tissues as a function of pregnant stage (64-MHz first-level controlled mode).