EMF exposure and temperature increase of anatomical pregnant women models within a 3T RF shimmed birdcage.

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TARGET AUDIENCE: For researchers in RF MRI safety.

PURPOSE: Magnetic resonance imaging (MRI) is a powerful non-invasive imaging technique, which is increasingly frequently used to scan pregnant women too. However, absorbed radiofrequency (RF) energy must be very carefully managed, especially as the highly conductive amniotic fluid is not perfused and thus has limited heat dissipation. The exposure scenarios of two-port I-Q RF shimming at 3T is investigated within this study, assessing the local SAR exposures and the induced temperature increase in typical imaging positions for pregnant women at several gestational stages.

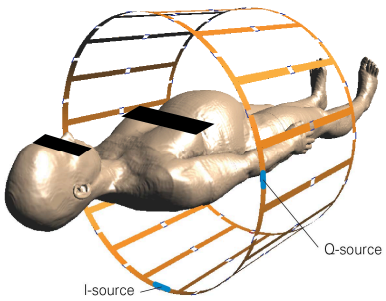

Fig. 1: Pregnant anatomical model, 7th month of gestation within generic 3T I/Q birdcage (shield not depicted)

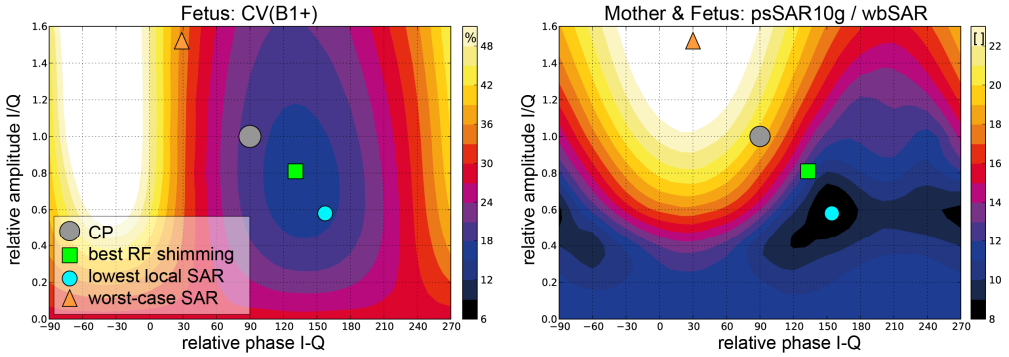

Fig. 2: (Left) CV(B1+) for the fetus as ROI, best RF shimming (lowest CV(B1+)) for 130° phase difference and 0.8 amplitude ratio of the I/Q sources. (Right) psSAR10g per wbSAR for the I-Q parameter space.

METHODS: The anatomical pregnant human model Ella [1] (3, 7, 9 months gestation), is evaluated in five Z-axis positions (heart to groin) within a generic 3 T body coil at 128 MHz. The simulation scenario is depicted in Figure 1.

The dielectric and basal thermal tissue properties have been assigned according to the comprehensive literature review of [2]. Two separate I and Q broadband simulations were performed and combined in post processing to evaluate the potential effects of RF shimming (shifts in relative phase and amplitude of I and Q). The covariance of B1+ (CV(B1+), defined as SD divided by the mean within the ROI) and the local SAR enhancements are evaluated and depicted in Fig. 2 for fetus-centered imaging position in 7th month gestation. Fig. 2 doesn't show the expected symmetry at 0° and 180° because of small-scale anatomy and posture asymmetries (left arm closer to torso, effect-magnitude under investigation). Thermal simulations were performed considering local thermoregulation [3] for the mother. Heat exchange through the umbilical cord was neglected. Exposures were normalized to the maximum allowance in the normal operating mode (wbSAR = 2 W/kg), the maximum exposure allowed for pregnant women.

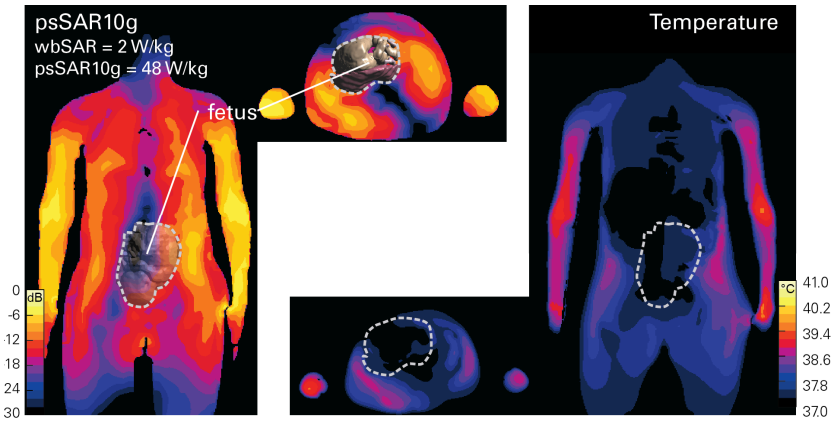

Fig. 3: psSAR10g normalized to 2 W/kg wbSAR (normal operating mode) for worst-case SAR IQ-configuration (I=1∠0°, Q=1.6∠30°), and peak temperature (steady state) including local thermoregulation. 0 dB = 48 W/kg.

RESULTS: The RF shimming parameter space for the 7th month of gestation in fetus-centered imaging position (Fig. 2) shows a CV(B1+) within the fetus of 12% (best shimming), 25% (CP mode), and >50% (B1- predominant). A mean B1+ level of 2.14 µT (best shimming) and 1.04 µT (CP) can be applied in normal operating mode (rms-time-average). SAR management must take into account the used scan-sequence. Local SAR enhancements in the mother reach from factor 8 to 24, relative to the wbSAR. This leads to maximum psSAR10g values of 48 W/kg for the worst-case exposure scenario, with wbSAR = 2 W/kg, fetus average-SAR is 1.6 W/kg, and amniotic-fluid average-SAR 3.4 W/kg. Scenarios with worst-case SAR and heating for the fetus as well as for different gestational stages and positions are under evaluation. For the evaluated worst-case SAR in the mother, the subsequent RF induced peak local temperatures reach up to 41°C in the mother. Within the fetus and amniotic fluid, temperatures remain below 38°C (Fig. 3). These values are smaller than estimated in [4] (38.7°C in the fetus and 40.1°C in the amniotic fluid) which is due to the modeled local thermoregulation of the mother. SAR values are comparable (1.05 W/kg and 2.74 W/kg for a CP excitation). Whether other RF shimming configurations may lead to a higher thermal load in the fetus is still under investigation.

CONCLUSION: RF shimming can increase the B1+ uniformity within the fetus by a factor of 2. Worst-case psSAR10g is obtained with almost linear polarization of B1, with a mainly vertical polarization axis. Local thermoregulation can have a strong impact on SAR induced heating. For worst-case SAR configurations of the mother, the fetus and amniotic fluid encounter moderate heating only, as the induced eddy-currents have their maxima in tissues with high radial distance. Worst-case configurations in terms of fetus heating are under investigation.

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REFERENCES: 1. Christ et al. 2010, PMB 55, 2. Hasgall et al. 2011, www.itis.ethz.ch/database, 3. Murbach et al. 2013, MRM doi: 10.1002/mrm.24671, 4. Hand et al. 2010, PMB 55.