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Optimized High-Permittivity Pads Can Reduce SAR and Increase Transmit Field Homogeneity in Fetal Imaging at 3T

Jeroen van Gemert[1], Wyger Brink[2], Rob Remis[1], and Andrew Webb[2]

[1]*Circuits and Systems Group, Delft University of Technology, Delft, Netherlands,* [2]*C.J. Gorter Center for High-Field MRI, Leiden University Medical Center, Leiden, Netherlands*

Synopsis

One of the main concerns in fetal MRI is the amount of power that is deposited both in the fetus and the mother. In this work, we show that a well-designed high-permittivity pad can tailor the energy of the RF field such that the transmit efficiency increases and the field becomes more homogeneous. The increase in transmit efficiency subsequently enables a substantial reduction in the SAR in both the mother and the fetus for models of the third, seventh, and ninth months of gestation.

Purpose

One of the main concerns in fetal MRI is the power that is absorbed both by the mother and the fetus. As a result, the allowed specific absorption rate (SAR) is limited to a whole-body SAR (wbSAR) of 2 W/kg. Studies have shown that the peak spatial SAR averaged over any 10 g of tissue (psSAR10g) can exceed the 10 W/kg limit.[1,2] Murbach et al. report that active RF shimming can lower the psSAR10g in the mother, but that it increases the value in the fetus.[3] Passive shimming using high permittivity materials in the form of flexible “dielectric pads” have been shown to improve the B_1^+ efficiency and homogeneity, while reducing the SAR, in different applications at 3T.[4,5] The benefits of dielectric pads in fetal MRI have been indicated previously, but these pads were not optimized and the different gestational stages were not taken into account.[6,7] In this work, we study the effect of optimized dielectric pads for the third, seventh, and ninth months of gestation, and show that the SAR can be reduced while the transmit homogeneity is increased.

Methods

For the simulations a wide-bore high-pass birdcage coil with a radius of 37.5 cm and tuned to 128 MHz (3T) was used. Pregnant models in the third, seventh, and ninth months of gestation (IT’IS foundation[8]), are positioned in the bore with either the center or the brain of the fetus placed at magnet isocenter, as shown in Figure 1. The electromagnetic field simulations and SAR evaluations are computed on a uniform and isotropic grid with a resolution of 7.5 mm and 3.75 mm, respectively. Transmit efficiency results were normalized to 1 W input power. Following the approach from other authors (e.g. Murbach et al.[3]), the SAR results were normalized to 2 W/kg wbSAR.

In previous work,[9,10] we developed an efficient approach to design dielectric pads using reduced order modeling and optimization techniques. Following this approach, we define a 1.5 cm thick pad-design domain layer around the belly extending from the groin to just below the breast, as indicated in Figure 1. The optimization techniques allow us to rapidly (~ minutes) determine the optimal pad’s geometry, location, and composition that either provide the highest B_1^+ homogeneity, expressed in terms of a coefficient of variation (C_v), or the best transmit efficiency in a region of interest (ROI). During the optimization, the width and height of the pad are restricted to 30 cm, the relative permittivity to a maximum of 300, and the conductivity is set to 0.2 S/m.

Two ROIs are evaluated: one encompassing the entire fetus and the other only the brain of the fetus (with the exception of the three months model in which only the entire fetus was possible). The model is placed such that the ROI lies at the magnet isocenter. One set of pads are designed that provide the best C_v and another set that provide the best transmit efficiency.

The SAR is evaluated in terms of avgSAR (the average SAR in a specific body part) and the psSAR10g in the mother, fetus, and the amniotic fluid. The SAR results are normalized with respect to the average B_1^+ field improvement in the ROI.

Results

The properties of the optimum dielectric pads are displayed in Table 1, where it is shown that a transmit efficiency gain of ~25% can be achieved at 9 months, ~54% at 7 months, and ~45% at 3 months. The C_v decreases in all cases, except for the 9 months case in which the values are very similar.

The B_1^+ fields and SAR results for the optimum transmit efficiency case are shown in Figure 2, which shows that the spatial distribution of the SAR is very similar to that without dielectric pads. The results show an overall decrease in the SAR values. Specifically, the avgSAR in the mother decreases by more than 31%, 55%, and 53% for the nine, seven, and third months of gestation, respectively. For the optimum C_v case the numbers are slightly lower, i.e. 17, 51% and 53%. Full details are listed in Table 2.

Conclusion

We designed high-permittivity pads for imaging the fetus in the third, seventh, and ninth month of gestation. We have shown that the SAR can be reduced while the homogeneity of the B_1^+ field is increased.

Acknowledgements

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Figures

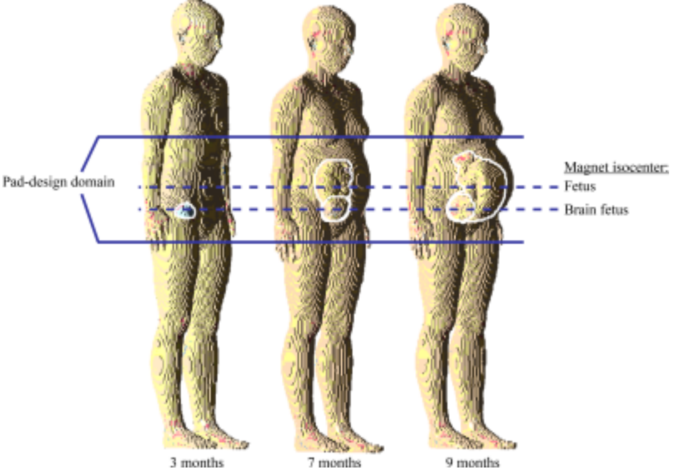

Figure 1. Pregnant body models in the third, seventh, and ninth months of gestation. The pad design domain confines the length of the pad in the head/foot direction region. The two magnet isocenters, the center and the brain of the fetus, are shown on the right-hand side.

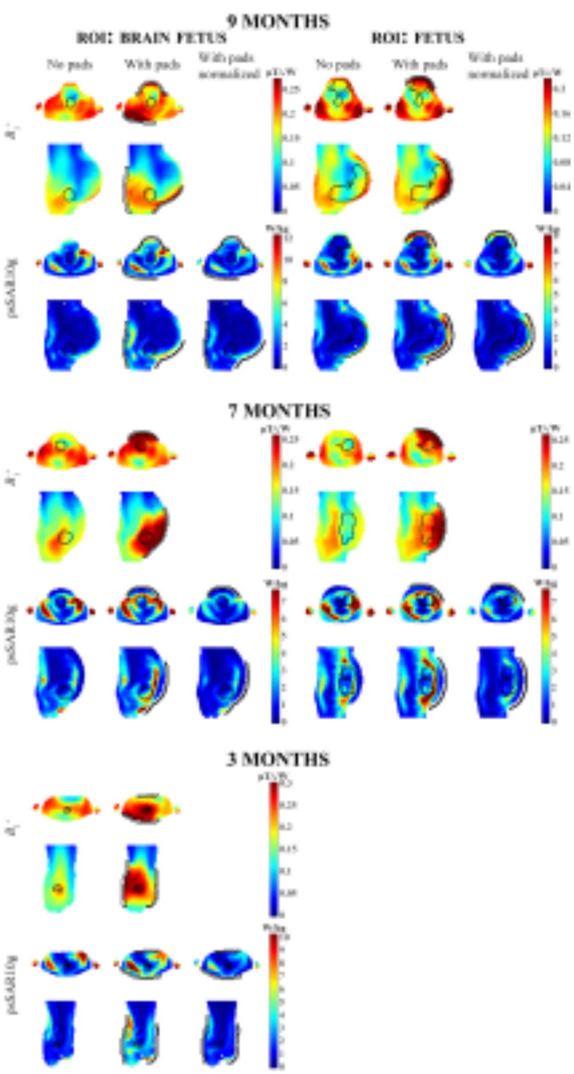

Figure 2. B_1^+ fields and SAR evaluations the for the three, seven, and nine months gestation. The first and fourth column are the results without any dielectric pad for the ROI set to the brain of the fetus and the fetus, respectively. The second and fifth column depict the results with dielectric pad, and the thirds and sixth column the results when normalized for the B_1^+, i.e. the same transmit efficiency in the ROI is achieved as in the case without dielectric pads.

	9 months		7 months		3 months	
Configuration	Transmit eff. gain (%)	C_v (%)	Transmit eff. gain (%)	C_v (%)	Transmit eff. gain (%)	C_v (%)
Fetal brain, best B_1^+	25.4	13.9 => 9.16	53.9	15.8 => 4.23	45.2	8.05 => 1.67
best C_v	17.8	13.9 => 6.53	52.2	15.8 => 3.20	45.2	8.05 => 1.67
Fetal average, best B_1^+	26.6	25.8 => 27.7	49.7	18.9 => 12.5		
best C_v	9.67	25.8 => 24.9	44.0	18.9 => 11.5		

Table 1. Summary of the B_1^+ transmit efficiency gains and the C_v with respect to the case without a dielectric pad.

Results are compared for the dielectric pad that optimizes the efficiency of the field and the homogeneity of the field.

	avgSAR (W/kg)			psSAR10g (W/kg)		
Configuration	Mother	Fetus	Amniotic	Mother	Fetus	Amniotic
9 months						
Fetal brain						
No dielectric pads	2.00	1.04	2.65	25.4	7.11	15.3
Pad best B_1^+ efficiency	1.39 (-31%)	0.88 (-15%)	1.90 (-28%)	15.6(-38%)	6.49 (-9%)	10.1 (-34%)
Pad best C_v	1.55 (-23%)	1.03 (-1%)	2.22 (-16%)	18.4 (-27%)	8.13 (+14%)	10.8 (-30%)
Fetal average						
No dielectric pads	2.00	1.01	2.80	29.3	7.48	15.1
Pad best B_1^+ efficiency	1.15 (-42%)	0.92 (-9%)	2.08 (-26%)	15.6 (-47%)	6.75 (-10%)	8.08 (-47%)
Pad best C_v	1.65 (-17%)	1.07 (+6%)	2.73 (-3%)	22.4 (-24%)	8.40 (+12%)	13.5 (-11%)
7 months						
Fetal brain						
No dielectric pads	2.00	2.00	4.35	19.8	12.8	13.7
Pad best B_1^+ efficiency	0.86 (-57%)	1.18 (-41%)	2.66 (-39%)	7.47 (-62%)	5.54 (-57%)	6.01 (-56%)
Pad best C_v	0.88 (-56%)	1.24 (-38%)	2.80 (-36%)	7.73 (-61%)	5.93 (-54%)	6.41 (-53%)
Fetal average						
No dielectric pads	2.00	2.32	5.02	24.4	14.9	16.1
Pad best B_1^+ efficiency	0.91 (-55%)	1.48 (-36%)	3.50 (-30%)	8.88 (-64%)	7.79 (-48%)	8.52 (-47%)
Pad best C_v	0.98 (-51%)	1.57 (-32%)	3.64 (-28%)	9.73 (-60%)	8.30 (-44%)	9.09 (-44%)
3 months						
Fetal brain						
No dielectric pads	2.00	1.6	1.32	22.1	2.68	2.91
Pad best B_1^+ eff. and C_v	0.94 (-53%)	1.33 (-17%)	1.13 (-14%)	9.66 (-56%)	2.03 (-24%)	2.04 (-30%)

Table 2. Summary of the SAR evaluations. All percentages in the avgSAR and psSAR10g columns are with respect to the original configuration, i.e. where no dielectric pads are being used.